Using EM and gamma maps to map soil types and help locate subsoil constraints for management

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Key messages

- Soil maps improve the targeting of sampling for constraint and nutrients management, as well as variable rate management.
- EM and Gamma farm maps can be overlayed to make simple soil type maps.
- Using low, medium and high gamma K or TC counts classes and low and high EM classes 6 soil types can be mapped to define areas of sand, saline sand, gravels, duplex soils, gravelly duplex and clay soils.
- Point data, such as soil texturing and soil chemistry and farmer knowledge were used to adjust and evaluate the gamma and EM classes.

Aims

The aim is to create simple paddock and farm scale soil maps, using ground based geophysics measurement of EM and gamma, for variable rate management such as nutrient or soil constraints. The main soils mapped, were defined after discussions with advisors and farmers about which soils they manage differently such as light versus heavy soils (i.e. sands vs. clays), gravels, and duplex soils (sand over clay, or loam over clay) where they would like to identify the depth to clay (pers com David Hall) (Table 1).

Previously EM and gamma maps were used separately, and the measurements were correlated to soil chemical properties such as cation exchange capacity (CEC), organic matter (OM), % clay and electrical conductivity (ECe) (Cook et al. 1996). Soil property zones were then created from these correlations based on statistical approaches, fuzzy classification or decision trees (McBratney et al. 2003). These maps were difficult for famers to understand, and not useful for management of soil constraints as farmers and advisors wanted soil units which related to farm management options.

Combining EM and gamma, to map four soil types was tested on a paddock in WA (Wong et al. 2008). We expanded this approach to map six soil types (Table 2) and tested the approach on 29 paddocks and one whole farm in WA (Figure 1).

Table 1. Commonly recognised and managed WA soil types (DPIRD MySoil types (van Gool et al, 2018), with descriptions, area in the Wheatbelt, soil constraints and common management practices.

DPRID MySoil type	Soil description	Area of WA wheatbelt (%)	Constraint	Management
Sands & Sandy Earths	Sandy texture throughout Sand grading to loam	24%	Low pH, compaction, non-wetting, nutrient leaching	Liming, ripping, mouldboard, non-wetting agents, nutrient timing
Gravels	Ironstone gravel (>20%) within 15cm from surface, greater than 20cm thick.	7.8%	Nutrient leaching, poor water holding capacity, non-wetting	Manage differently and care with deep ripping, nutrient timing
Duplex soils *	Sandy or loamy surface texture. Abrupt change to sandy clay loam or clay.	32%	Low pH, compaction Shallow or deep duplex*, depth to duplex	Liming, ripping, spading, mouldboard, delving (depth dependant)
Gravelly duplex	Gravel over rock or clay at < 80cm	8.2%	Low pH, Non-wetting Clay subsoil may have salinity or sodicity	Liming, nutrients Gypsum, OM amendment Care with management
Clay & Shallow loamy duplex	Loamy or clayey surface texture and clayey subsoil Loamy surface texture, abrupt change to clayey subsoil	15%	Salinity, Sodicity, Boron	Gypsum, OM amendments, slotting, water harvesting

* Shallow duplex = abrupt texture change at 30cm or above, deep duplex =abrupt texture change between 30 and 80cm

Method

The ground based measurement of EM and Gamma as well as point data of soil descriptions, soil chemistry and PAWC measurements were sourced from the GRDC invested Subsoil Constraint project (DAW00242) and additional sites from previous GRDC invested precision agriculture projects. The case study sites included 16 farmers, 29 paddocks (2733ha) plus 1 whole farm (>20 paddocks, 2466 ha) and 355 soil sampling points (Table 3). Sites were spread across the WA wheatbelt (Fig 1). In this paper we present results from a case study in the Northern region (N1) to describe the methodology developed.

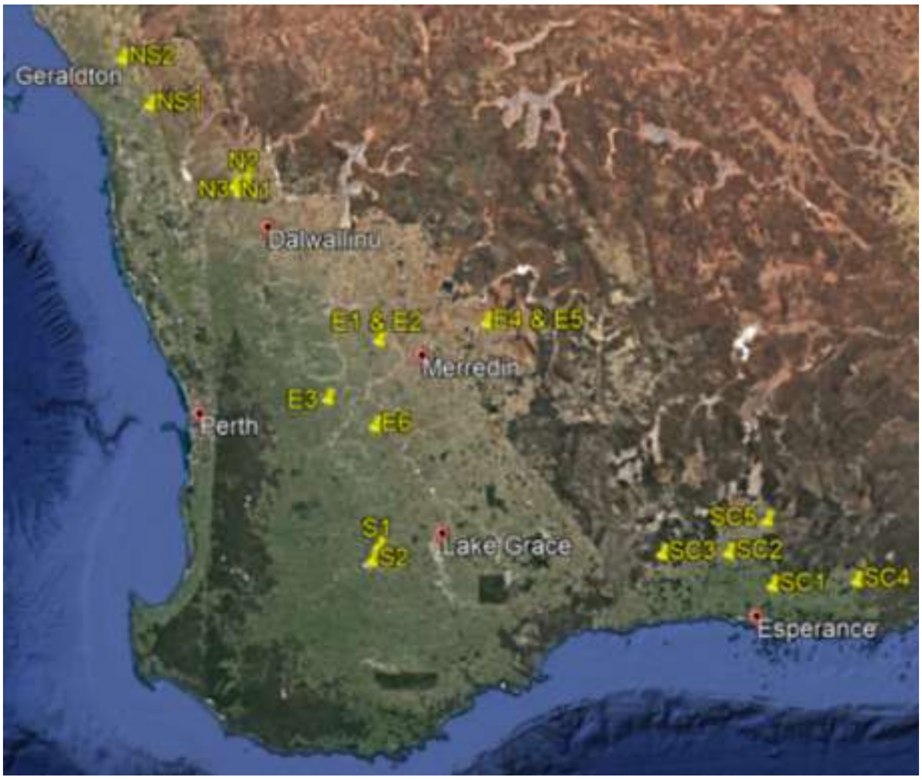

Fig 1. Location of the case study paddocks with geophysics and point soil measurements in WA.

Soil point data was assigned to a WA soil class (van Gool et al 2018, MySoil), using available data which could include: hand texture, gravel, particle size analysis (PSA), plant available water capacity (PAWC), soil chemistry and visual descriptions in layers up to 1 m depth. Soil descriptors from hand texture used:

- Sandy soils - fine, medium and coarse sand, loamy sand and clayey sand - 5-10% clay
- Loamy soils - sandy loam, loam, silty loam, sandy clay loam and clay loam – 10-35% clay
- Clayey soil - light, medium and heavy clay, sandy and silty clay – >35% clay
- Duplex soils – have an abrupt texture change (>20% difference in clay content), with shallow duplex change occurring at <30cm and deep duplex change between 30 and 80cm
- Gravel soils – greater than 20% gravel Ironstone gravel within 15cm from surface, greater than 20cm thick.

Gamma and EM measurements were smoothed to a 10m x10m grid spacing using kriging. The EM readings are related to water content, salts in the soil (EC) and clay content. The EM values, were separated into low and high classes and mapped using red and blue colours (Table 2). The gamma (K counts or total counts) correlates with clay and gravel content. The gamma counts were separated into 3 classes, low, medium and high and assigned a dark grey, light grey or yellow colour respectively (Table 2) and mapped with a 50% transparency. The gamma and EM maps were then overlayed to produced 6 colour classes which roughly correspond with broad soil types, eg. MySoils (Table 2). The EM and gamma cut-off values were based on the point data for the various locations.

The combination of EM and gamma can improve the mapping of the major soil differences, compared to just using them individually. This is due to the combination of sands, clays, gravels and salts in the WA soils. For example, low gamma is associated with sandy soils with the EM used to determine if the sand is saline or not. High gamma is related to clay and clay/gravel soils and EM can separate these two soils as clay soils usually have a higher EC compared to gravel. Medium gamma means there is some gravel or some clay but there is also sand present, usually associated with duplex soils (sands over clay) and sandy gravels. In this case the EM is able to separate these to soils as the gravels have low EC, while the duplex soils has a higher EM due to the clay subsoil (Table 2).

Table 2. Overlaying the gamma (with 50% transparency) on the EM layer produces 6 colours, which are correlated with the major WA soil groups

Gamma	EM	WA MySoil type and Map colour
Low	Low	Sand and Sandy earth
Low	High	Coloured sand – saline/ loams
Medium	Low	Gravel
Medium	High	Duplex soils
High	Low	Gravelly duplex
High	High	Clay and shallow loamy duplex

Results

We show one of the case study sites (3 paddocks of N1) where using the soil point data the gamma K classes were low <40 counts, medium 40-70 counts and high >70 counts, and the EM values were low at <20 units and high at > 20 units. The table shows the point ID with the soil description from hand texturing and the colour of the cell indicates the colour/soil type from the mapping. The only site where the description did not match that from the mapping was site 5, a deep duplex soil was mapped as a gravel.

Table 3. Soil points with their ID number, soil description and mapping soil type (colour of cell) for three paddocks at Site N1 (Figure 2.).

Point ID	Soil Description	Point ID	Soil Description	Point ID	Soil Description
1	Sand	3-20	shallow gravel duplex @ 30cm	5	deep duplex @ 60cm
2-10	Sand	14	shallow gravel duplex @ 25cm	11	deep duplex
2-20	Sand	15	deep duplex @55cm	8	deep duplex @80cm
12	sand	13-10	deep gravel duplex @40cm	10-10	shallow duplex @25cm
9	sand	13-20	deep gravel duplex @40cm	3	shallow duplex @25cm
6	sand	3-10	deep gravel duplex @ 50cm	10	clay
7-10	sand				
4	sand				
7	sandy earth- loamy				

In this example (N1), the EM layer separated the high gamma areas into gravels and clays (Figure 2). The medium gamma class was separated into gravelly sand and duplex soils by the EM cut-off level used. This example shows that the combination of EM and gamma is required to map soils on this farm.

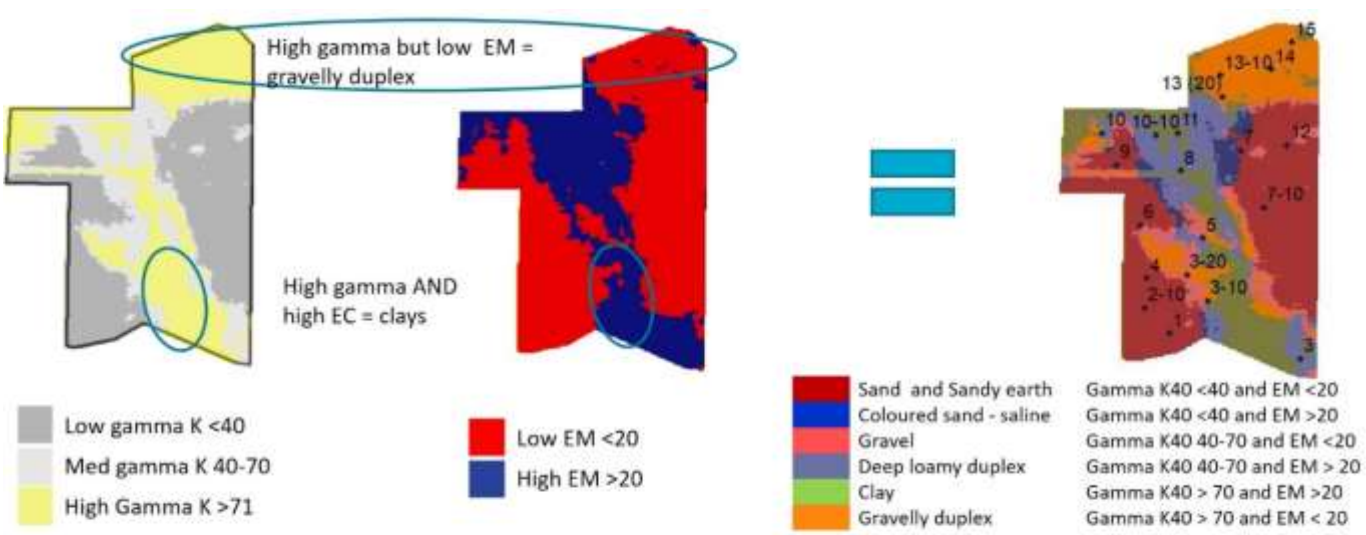

Figure 2. The gamma K separated into 3 classes, the EM separated into 2 classes and the subsequent soil map from overlaying the two layers for Case study N1.

For the northern sandplain cases, the classes required some refinement (Table 4). The gamma was low as the paddocks consisted of mostly sandy soil types and did not have ironstone gravels or clay soil types. For these sites, the gamma was split into 2 classes, with no high gamma class. For NS1, the low gamma was the quartz gravel soils and the medium gamma with low EM the sand, and medium gamma with high EM the deep sandy duplex. For NS2, the low gamma with high EM was a sandy earth, and the medium gamma with low EM the sand (there was only 2 soil classes on this paddock). It is important to note that the divisions between soil types are relative, using these mapping techniques, and will not always correlate precisely with formal soil classes.

We applied this methodology across the remaining case studies and found the cut-off value for the high gamma class was similar to the mean of the gamma for the paddock (Table 4). For 2 farms, at Kellerberrin (E1, E2) and Bodallin (E4 and E5), the individual paddocks did not have the full range of the gamma but when they were combined, the average gamma was near the cut-off values chosen. The low gamma cut-off value is similar (but not quite) to the mean subtracting 0.6 x Standard deviation. At some of the sites, the mean was also useful as a first estimate to separate the low and high EM classes. Other spatial information such as terrain attributes e.g. elevation above sea level, slope, etc. could also be introduced to further differentiate likely differences in soil types.

Table 4. Description of available data across all sites, paddock size, number of soil samples and gamma and EM (mean & standard deviation (SD) results for estimating mapping cut off values.

Site	Nearest town	No pdk	Area (ha)	No points	Gamma					EM		
					type	mean	SD	Mean-0.6*SD	Cutoffs Low, High	mean	SD	Cutoffs
Northern												
N1	Coorow	3	243	32	K	**68**	49	39	40 **70**	22		20
N2	Buntine	3	168	26	K	**82**	38	59	50 **80**	32	35	20
N3	Buntine	3	265	41	K	**67**	34	47	40 **70**	21	11	25
Northern sandplain												
NS1	Mingenew	2	87	13	TC	148	20		135 --	15	2	15
NS2	Erudu	1	59	4	TC	183	12		170 --	1.2	0.5	1.9
Eastern												
E1	Kellerberrin	1	67	9	K	40	22			9	8	15
E2	Kellerberrin	1	69	6	K	85	52			22	21	
E1+E2			136			**62**	37	40	40 **70**			
E3	Greenhills	2	142	8	K	**61**	17	51	30 **60**	50	30	15
E4	Bodallin	1	150	6	K	114	9			111	29	82
E5	Bodallin	1	115	21	K	56	17					
E4+E5			265			**83**		77	45 **70**			
E6	Corrigin	3	89	15	K	**18**	13	10	13 **20**	7	4.5	10
South												
S1	Dumbleyung	3	332	21	Kconc	**1.27**	0.3	1	0.75 **1.25**	146	53	110
S2	Dumbleyung	>20	2466	68	Kconc	**1.27**	0.52	1	0.93 **1.25**	74	61	45
South Coast												
SC1	Myrup	1	79	15	K	**11**	3.6	9	- **12**	46	25	85
SC2	Scaddan	1	325	26	K	**27**	8	22	15 **25**	128	48	40
SC3	Munglinup	1	195	17	K	**14**	5	11	8 **13**	131	56	55
SC4	Howick	1	164	16	K	**13.7**	2.5	12	9 **14**	44	14	50
SC5	Salmon Gums	1	183	11	K	**17**	6	13	12 **15**	111	48	100

Conclusion

Simple soils maps which can be used for management of nutrient and subsoil constraints can be created by overlaying farm scale EM and gamma spatial layers. Splitting the gamma into 3 classes and EM into 2 classes enabled differentiation of up to six soil types. Using the mean and standard deviation of gamma to estimate the class cut off values and the mean for EM is a good starting place for mapping different soils for practical management applications and can be refined with farmer knowledge and soil description sites. Using one soil type at a time, we can use the good areas to benchmark the yield the poor areas should be achieving. Farmer knowledge, visual observation and soil sampling of the poor areas of a soil type can then identity the likely nutrient and soil constraints. Once the constraint and area of the constraint is identified the economic analysis tools such as ROSA (Ranking options for Amelioration) (Petersen et al. 2018) can be used to decide which of these poor areas to target for future removal of soil constraints.

Future work on determining depth to clay using on-the go sensors would improve this mapping to enable the duplex soils to be managed particular for delving and other soil mixing amelioration strategies.

Key words

Precision agriculture, soil mapping, gamma radiometrics, EM mapping

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