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Soil management calculator (SMCAL) - Making nutrient and lime recommendations, and environmental impact assessment for the cropping and pasture systems of Western Australia

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Soil Management Calculator (SMCAL) combines various soil nitrogen (N), sulphur (S), phosphorus (P), potassium (K), copper (Cu), zinc (Zn) and soil acidity routines into a single model for making soil management decisions. It also provides an assessment of the environmental impact of agricultural land use in terms of its impact on leakage (loss of water below the root system) and nutrient loss associated with P runoff, nitrate leaching, nitrous oxide emissions and product removal. SMCAL provides a linkage between the nitrogen cycle, soil acidity management and product removal for the calculation of soil acidification rates. Currently SMCAL does not provide routines to calculate soil nutrient depletion because it is assumed farmers undertake regular soil testing to detect nutrient decline associated with agricultural production. Phosphorus runoff and nitrous oxide emission calculations were made possible due to the development of water balance routines (evaporation, leakage and runoff). SMCAL also adopts the APSIM approach for defining the plant available water holding capacity of different soil types. Hence, it is possible to calculate amount of water leakage from the soil profile. This value is especially important in WA due to the nature of the soils (low water holding capacity) and climatic conditions (intense June-July rainfall) and the resulting impact on calculated potential yield and N and S use efficiencies. The project is funded by GRDC, DAFWA and Murdoch University.

Topsoil pH is a poor indicator of subsurface soil pH and lime requirements in agricultural soils of south-west Western Australia.

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The aim of this work is to assess the value of soil pH profile information for better management of soil acidity in WA. Soil acidity is recognised as a threat to sustainable agriculture in south-west Western Australia. Annual productivity losses of $300–400 million have been estimated and are predicted to continue and increase unless adequate agricultural lime is applied. Surveys have shown that approximately 1 Mtpa of agricultural lime has been applied in both the 08/09 and 09/10 years. Typical application rates are 1 t/ha, and are generally inadequate to remove acidity as a constraint to productive agriculture. Surface and subsurface soil pH values are required to produce an accurate lime recommendation. Lime application is generally not well targeted as most farmers only measure topsoil pH. Without subsurface soil pH data, lime recommendations are presented as a range to allow for situations with and without subsurface acidity. Subsurface acidity is known to exist in approximately 50% of the WA wheatbelt. We collected and measured the pH_{Ca} of more than 46,990 soil samples from the 0–10, 10–20 and 20–30 cm layers from the central wheatbelt of WA between 2005–2011. Our data shows topsoil pH is not a good indicator (r^2 0.4) of subsurface pH. When subsurface acidity limits production, higher rates of lime are required. Using the minimum of the range of an estimated lime requirement results in the correct amount of lime being prescribed in only 50% of cases. Similarly, using the maximum of the estimated range is correct only 15% of the time. The ‘default’ application rate of 1 t/ha supplied the correct amount of lime in <36% of cases. Understanding the soil pH in the topsoil (0–10 cm) and subsurface soil (10–20 and 20–30 cm) is essential to determine the appropriate lime requirement and economical application of a 10-year liming strategy to ameliorate both surface and subsurface acidity. Substantial costs and inefficient use of energy and resources occur when insufficient lime is applied to acidic soil or lime is applied unnecessarily to areas that are not constrained by acidity.

Acidification of a sandy aquifer with declining rainfall and increasing abstraction: implications for groundwater management with climate change

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The combined effects of low rainfall and increasing groundwater abstraction has caused the water table to decline by up to 5 m in a sandy, unconfined aquifer in Perth, Western Australia. Shallow groundwater has become acidic in areas of high drawdown, with pH values being typically 3.0-5.0 at the water table and concentrations of Al, Fe and Zn commonly being at levels of environmental concern. Column studies undertaken with sediments collected below the water table indicate that the pH of leachate can drop from 6.0-7.0 to about 3.0-4.0 within 2 months of being exposed to oxygen, which is consistent with pH declines observed in monitoring data from many urban development sites where groundwater dewatering is undertaken for the construction of deep sewers. Detailed mineralogical analysis of aquifer sediments indicates that the acidification is likely to be caused by the oxidation of sub-micron sized crystals of pyrite in material that has a chromium-reducible sulfur content of below 0.03%, less than the currently recognised national trigger value for sandy acid sulfate soil materials. A number of wetlands in the area have acidified due to water table decline, and there is a risk that increasing levels of soil and shallow groundwater acidity will affect the health of Banksia woodlands in the region.

Demonstration of precision agriculture (PA) principles in the Great Southern of WA

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The discrepancy between what can be done with Precision Agriculture (PA) and what is actually done in the field has been addressed by a Grain Research of Development Corporation (GRDC) funded project which consisted of a combination of training and field demonstrations and is presented in this paper. Familiarising growers and agribusinesses with the PA 'tools of the trade' allowed them to apply those more effectively. This was done through a sequence of series of workshops across the region at different times of the year. The practical demonstration of PA is done through a number of (17) on-farm demonstrations whereby different rates of inputs are varied across different soil types. This is considered a good and simple way of assessing the effectiveness of varying input by management zones. These zones were established from previous yield maps and/or soil conductivity maps. The number of growers, agronomists and consultants varied from 2 to 25 in each of the workshops. In total about 40 growers were reached in each series. In 2010, which was exceptionally dry, varying the input rates by soil type had very little effect on the yield. Even eliminating the fertiliser inputs had very little consequences for the final yield. Therefore the lowest rates of input were always the most economical which illustrates the possible financial gains from PA. The trials are continuing in 2011 with at this stage little also little impact on biomass.

Developing a functional soil from bauxite-processing residues

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Sustainable plant establishment on ore processing residues requires development of a functional soil, which includes the introduction of organic matter and establishment of active microbial communities. The hostile chemical, physical and biological characteristics of bauxite-processing residues represent a significant challenge to its rehabilitation. Australia is the world's largest producer of bauxite, which undergoes refining to produce alumina. In Western Australia, three alumina refineries generate approximately 15 Mt per annum of residue, which is separated into coarse (sand) and fine (mud) fractions and place in residue storage areas. We investigated the development of microbial diversity and function in residue sand embankments that had undergone rehabilitation with native vegetation, using a 3-year chronosequence design. Contrary to our original hypothesis, the diversity of the bacterial and fungal community (assessed by Automated Ribosomal Intergenic Spacer Analysis) developed rapidly and within six months was similar to a natural coastal sand. Significant shifts in microbial community structure with rehabilitation age were also evident. However, the microbial biomass in residue sand remained low (< 50 mgC kg^{-1}), and appeared most limited by organic matter availability. If supplied with a labile C source (amino acids), the residue sand microbial community was capable of rapid mineralisation (amino acid half-life of 3.8-6.2 h). Current amendments of residue sand include incorporation of phospho-gypsum, to reduce the pH, and application of di-ammonium phosphate-based fertiliser prior to seeding. However, this study suggests that further amendments may be required to alleviate longer-term nutrient availability limitation as well as water availability limitation (residue sand has high hydraulic conductivity and rehabilitation is non-irrigated) to plant growth. A further study is underway to test the effect of textural and organic matter amendment of residue sand on its water holding capacity, nutrient availability, below-ground biomass and activity and ability to support plant growth.

Strategic soil measurements enable better assessment of yield variation in cereals under conditions of terminal drought

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We measured the growth of 50 cereal genotypes (43 wheat and 7 barley cultivars) on a sodic soil at Merredin. Our experiment had adjacent blocks with a water adequate treatment ["wet" block; ~100% of long-term average rainfall (~300 mm); established with supplementary irrigation] and a droughted treatment ("dry" block; ~50% of long-term average rainfall; established using rainout shelters installed 93 days after sowing, and 10-25 days before anthesis). Soil factors likely to impact on plant growth were surveyed across the two blocks on two occasions in spring of the year of growth and in February after harvest. Altogether, we collected more than 4700 data relating to soil conditions, and these were used to create a profile of each plot.

Average grain yields in the dry block were decreased by ~70%, due mainly to the decreased water supply. However, within this treatment a range of other soil factors had sufficient effect on yield for them to be useful covariates. Wheat yields in the dry block were decreased by a family of covariates associated with high Mg in the saturation extract (Ca^{2+}, S, K^{+}, Cl^{-} and Na^{+} in the saturation extract, $EC_{1:5}$ and north-south orientation of the plots). High Mg is known to decrease the hydraulic conductivity and hence, leaching of salts, through soils. Concentrations of Mg in the saturation extract at 0-25 cm depth varied between ~0.5 and 2.6 mM, and average wheat yields decreased from ~250 to 130 g/5m^2 plot over this range. We do not believe that Mg was toxic to plants at this site; rather high Mg (and its associated problems) decreased growth because of increased osmotic stress, and/or decreased infiltration of water into the subsoil.

Plant breeders usually correct spatial trends in yield trials using appropriate statistical models; however this does not further our understanding of what is driving plant performance within a particular trial/ environment. We have provided evidence that strategic soil sampling based on the spatial variation observed in a trial has the potential to significantly increase our understanding of the traits responsible for performance in that environment. Our data show that in slowly leached sodic soils, this can be done retrospectively after harvest at relatively low cost.

The contribution of soil N_2O emissions to the carbon footprint of wheat and biodiesel production in Western Australia

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Correctly accounting for soil nitrous oxide (N_2O) emissions is necessary when assessing the carbon footprint of agricultural and bioenergy cropping systems. Although soil N_2O emissions appear low in relation to N fertiliser inputs [e.g., 1.0% if Intergovernmental Panel on Climate Change (IPCC) default factor employed], the high global warming potential of N_2O (298 times greater than CO_2), and the increasing amount and area to which N fertiliser is applied, means accurate estimates are required when calculating net greenhouse gas (GHG) emissions from grain and biodiesel production. We measured soil N_2O emissions from a rain-fed, cropped soil in a semi-arid region of the Western Australian grainbelt for three years on a sub-daily basis. The site included N fertiliser (75–100 kg N ha^{-1} yr^{-1}) and no N fertiliser plots ('control'). Emissions were measured using soil chambers connected to a fully automated system that measured N_2O using gas chromatography. Daily N_2O emissions were low (-1.8–7.3 g N_2O-N ha^{-1} day^{-1}) and culminated in 0.09–0.13 kg N_2O-N ha^{-1} yr^{-1} from the N fertiliser soil and 0.07–0.09 kg N_2O-N ha^{-1} yr^{-1} from the control. The proportion of N fertiliser emitted as N_2O each year, after correction for the control emission ('background'), was 0.02–0.07%. The emission factor was up to 50 times lower than the IPCC default value for the application of synthetic fertilisers to land (1.0%). Incorporating locally measured N_2O values greatly decreased the carbon footprint of wheat and biodiesel produced from the Western Australian grainbelt. Greenhouse gas emissions decreased from 487 to 304 kg CO_2-equivalents per tonne of wheat using local N_2O emissions rather than the international default value. Furthermore, utilising locally measured soil N_2O fluxes decreased GHG emissions from the production and combustion of one GJ canola based biodiesel from 63 CO_2 to 37 CO_2 equivalents; with GHG emissions up to 2.1-times lower than that from the production and combustion of one GJ mineral diesel. We recommend utilising regionally specific estimates of direct soil N_2O emissions, and include estimates of indirect N_2O emissions, when assessing GHG emissions from grain and biodiesel production from agricultural soils.

Roadside survey technique to assess the trends in land use, land management and soil condition of geo-located sites in the wheatbelt of Western Australia.

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The monitoring of soil condition over large areas is problematic, particularly wind and water erosion. A national project on assessing soil erosion through roadside survey (RSS) techniques was started in 2007 with the aim of standardising the observation procedure across Australia. The current WA RSS began in 2007 and has been operating across the wheatbelt since then. The RSS has been monitoring the occurrence of wind and water erosion as a value of the soil condition.

The RSS consists of a series of 16 transects selected to give a good distribution of geo-located sites across DAFWA agricultural regions and geographical land system zones, with a total of over 3000 individual sites and a road distance of about 6,000 km. Each site is 100 m x 100 m located in the observed paddock, with the quadrat some 50m from the road, fencelines and paddock headlands. The site is assessed for percentage ground cover, soil texture, slope, vegetation height, soil detachment, wind and water erosion, land use and land management. From the observations, erosion hazard is calculated as a function of cover x texture x detachment, reported from nil to very high in six intervals. The transects are traversed twice yearly; once at maximum biomass (October-November) prior to harvest, and the second at minimum biomass (April-May) prior to seeding.

The sites, when associated with property titles, approximate 10% of the total land holdings in the wheatbelt and cover all but two local shires. All major land systems also have some sites. The observations, to date, have identified that 2007 in the northern agricultural region was a very poor year, with respect to erosion, compared to the drought of 2010 in the central agricultural region (CAR). Management of the Dry Season Response to the CAR was modified by the results of the RSS in 2010/11, particularly the adequate cover and low hazard rating observed in the summer traverse in January 2011.

This presentation will also cover the rationale behind the methodology and outline the additional products coming out of the RSS that can be used to identify practice change in the animal and grains industries.

Improving fertiliser management: redefining soil test-crop response relationships for canola, wheat and lupins in Western Australia cropping systems

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Fertiliser input is one of the largest variable costs for grain production. This paper reports on a study (funded by the GRDC) to re-examine the soil test–crop response relationships from trial data to define critical soil test values (P, K and S) for major crops (wheat, canola and lupin) grown on the soils of Western Australia. Initially we created a database of fertiliser experiments conducted mostly by the DAFWA going back to the 1970's. The data on wheat (418), lupin (420) and canola (266) single-year fertiliser experiments were compiled and analysed to derive critical soil test values. Canola grain production occurs on most soils in the region. Derived critical Colwell soil test values (mg/kg) for the top 10 cm of soil were 25 for P and 52 for K, which adequately indicated when canola crops were likely to respond to fertiliser P and K applications. The derived critical KCl40 soil S test value was 10 mg/kg. However, the critical S value could only be used as a general guideline due to the poor correlation between top (0-10cm) soil test and crop grain yield response. It is suggested that for the soils where the soil S test value for the top 10 cm was below the critical value, soil test values for the 10-20 and 20-30 cm horizons were also required. If soil test S was above the critical value (10 mg/kg) in either of these 2 lower soil horizons, then canola grain yield response to applied fertiliser S was unlikely. Wheat critical Colwell soil P test value varied (15-39 mg/kg) with soil types due to the differences in soil P sorption. For wheat crops grown on soil types other than duplex soils, the derived critical value (mg/kg) for Colwell soil K test was 80. Critical values of soil Colwell P for lupins varied with soil types due to differences in soil P sorption. For soil types with PRI <=1, the critical value was 25 mg/kg. But for soil types with PRI =>2, the relationship between Colwell soil P test and relative yield was poor. The derived critical value of Colwell soil K test for lupins was 31 mg/kg. Further improvements in estimated critical values using different curving fitting approaches and critical ranges (rather than single value) were also reported.

Phenotypic variability and modelling of root structure of wild *Lupinus angustifolius* genotypes

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Root plasticity in response to the edaphic environment represents a challenge in the quantification of phenotypic variation in crop germplasm. The aim of this study was to use various growth systems to assess phenotypic variation among wild genotypes of *Lupinus angustifolius*. Ten wild genotypes of *L. angustifolius* selected from an earlier phenotyping study were grown in three different growth systems: semi-hydroponics, potting-mix filled pots, and river-sand filled pots. Major root-trait data collected in the present study in the semi-hydroponic growth system were strongly correlated with those from the earlier large phenotyping trial. Plants grown in the two solid media had some of the measured parameters significantly correlated. Principal component analysis captured >87% of total variability in three (semi-hydroponics) or four (solid media) principal components. The genotypes were grouped into five clusters for each growth media, but cluster composition varied among the media. We found genetic variation and phenotypic plasticity in some root traits among tested genotypes. Using input parameters derived from the semi-hydroponic phenotyping system, simulation models (ROOTMAP and *SimRoot*) closely reproduced the root systems of a diverse range of lupin genotypes. Wild *L. angustifolius* genotypes displayed genetic variation and phenotypic plasticity when exposed to various growth conditions. The consistent ranking of genotypes in the semi-hydroponic phenotyping system and the two solid media confirmed the capacity of the semi-hydroponic phenotyping system of providing simple and relevant growing conditions. The results demonstrated the utility of this system in gathering the data for parameterising the simulation models of root architecture.

Application of *Scleroderma* in plantation forestry

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Scleroderma is often associated with plant roots in native forests and blue gum (*Eucalyptus globulus*) plantations in south-west Australia. This report summarised recent studies in the mycorrhizal genus of *Scleroderma*, and highlights technologies related to its applications in plantation forestry with particular references to Australasia. *Scleroderma* mycelia have unique characters which differ with other mycorrhizal fungi. In pure culture, *Scleroderma* mycelia are smooth, pure white, and differentiated rhizomorphs often radiate through the growth medium. Mycorrhizas of *Scleroderma* are characterized by distinctly white, glabrous to sparingly tomentose, with mantle mycelium often giving rise to concolorous mycelia. At the genus level, *Scleroderma* has a wide host range including some Northern Hemisphere and Southern Hemisphere trees in unrelated families (e.g. Pinaceae and Myrtaceae), but host specificity exists in some species. Due to the availability of large quantities of spores from a few basidiomes and the ease of application for nursery inoculation needs, spore inoculum is preferable for application on an operational scale in many countries. Studies demonstrates that spore inoculum of *Scleroderma* is efficient for plantation species including *Eucalyptus*, *Pinus* and *Acacia*. Effects of rooting media on mycorrhizal development are discussed although very little attention has been received especially with spore inoculation. In Australia, commonly used pine-bark potting mix in eucalypt nurseries has been shown to be less efficient for mycorrhization. Optimisation of rooting medium is required to incorporate inoculation and seedling production. *Scleroderma* has shown great potential to inoculate seedlings of woody plants in assisting establishment of plantations and promoting host growth in the field.

Farming systems for water repellent agricultural soils of Western Australia

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It is estimated that 3.3M hectares, 18%, of agricultural soils in south-west WA are at high risk of water repellence and 6.9M ha at moderate risk. Strategies to manage soil water repellence include:

1) Mitigation strategies
   i. Furrow sowing with press wheels, 'harvests' water into the sown furrows. Increased lupin yields by 40% on average compared with level sowing. In some knife point seeding systems repellent soil is falling into the open furrow with the seed and fertiliser reducing efficacy. Use of winged seeding points or boots to grade the repellent soil away from the furrow improved wheat establishment by 11% on mildly repellent soil to more than double in strongly repellent soils.
   ii. Banded wetting agents are short lived surfactants applied to the furrow base. Can increase crop establishment by an average of 30% over furrow sowing alone. Efficacy can be reduced as a result of soil movement during application or furrow infill.
   iii. Blanket wetting agents are longer-lived (2 years) surfactant and humectant blends, boom spray applied. Efficacy is soil type specific with best responses on repellent loamy gravels.
   iv. Zero-till, full stubble retention is a long term mitigation strategy in which undisturbed remnant roots and crowns provide sufficient pathways for water entry into repellent soils. May need to be combined with another strategy so sufficient plants can be established initially on highly repellent soils.
2) Amelioration strategies
   i. Deep cultivation involves soil inversion or lifting of wettable subsoil seams to the surface. Wind erosion is a high risk in the short term. Cereal yield increases have averaged 500-600kg/ha in the first year and 300kg/ha in subsequent two years. Additional benefits include improved weed control, reduced soil compaction and opportunity to incorporate lime.
   ii. Incorporation of clay-rich subsoil from delving or excavation into the non-wetting topsoil can overcome the problem for >10 years. Success depends upon the efficacy incorporation and nutritional value of applied subsoil. In successful trials crop yields have been increased by 20-100% over an eight year period.
3) Adaptation strategies
   i. Alternative land uses usually involve growing of well-adapted perennials on highly repellent low productivity soils.

Acid sulfate soils and management of groundwater – Translating science for management

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Understanding of acid sulfate soil (ASS) hazards in WA has gradually increased during the last decade enabling improved water resource management. However, for this to continue there is a need for viable management options at landscape scales. We present two case-studies illustrating how greater understanding of ASS on the Scott Coastal Plain and similar conditions in the Wheatbelt has informed water management. ASS have been investigated on Scott Coastal Plain in several programs progressively improving knowledge of the extent and nature of the hazard. Results from these have refined the regional extent of the hazard as well as the association with watertables and groundwater dependent ecosystems (GDE's). This understanding has become a valuable proxy for environmental water requirements for GDE's and has been used in assessing various water resource management options using regional groundwater modelling. In the Wheatbelt, acidity problems were recognised in saline groundwater that resulted in the formation of ASS conditions in floodways and lakes. The sediments in these environments exhibited chemical and mineralogical characteristics similar to ASS with similar effects on aquatic chemistry. Research found the acidic soils have been forming for some time in primary and secondary salinised floodways and lakes. However, formation might be accelerated by unmanaged discharge of acidic waters from groundwater drains. This understanding has focused management on identifying and mitigating acidic drainage discharge (including treatment) to prevent formation of ASS conditions, rather than preventing disturbance of ASS materials. Both case-studies show that greater understanding of ASS hazards have set the foundation for advice on future management, but further effort is required to move from hazard definition to practical management at scales relevant to WA.

Sporadic effects of biochar on organic nitrogen decomposition

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Biochar, the remains of thermal decomposition of organic matter, is an amendment proposed to sequester carbon and improve soil fertility. One critical aspect often limiting agricultural productivity is the conversion of organic nitrogen (N) to more readily plant available inorganic N. This experiment assessed how biochar amendment influences the decomposition of organic N compounds. Soil was collected from two biochar field trials; at Buntine, Western Australia; or at Abergwyngregn, North Wales. Uniformly ^{14}C-labelled organic N compounds either a mixture of 15 amino acids; alanine; or tri-alanine; were added to either soil from the control plots (control treatment); biochar amended plots (aged biochar treatment); or soil from the control plots amended with fresh biochar (fresh biochar treatment). The biochar amendments were 4 t ha^{-1} of wheat chaff biochar in the Australian soil, and 25 t ha^{-1} of mixed hardwood biochar in the Welsh soil. Both biochars were pyrolysed at 450 °C. 10 g of soil or biochar amended soil was added to 50 cm^3 polypropylene tubes. Organic N and NaOH traps (to capture respired $^{14}C\text{-}CO_2$) were added to the tubes, tubes were sealed and incubated at 20 °C. Traps were replaced over 20 days. An exponential kinetic decay model was subsequently fitted to the mineralisation data. Overall, statistical analysis revealed significant but small differences between the two biochar treatments and the unamended control treatment. We conclude that biochar has very limited impact on the mineralisation rate of low molecular weight dissolved organic N compounds in soil, and that biochar application is unlikely to influence agronomic N fertiliser recommendations, at least within the first few years of biochar application.

Towards a philosophy of soil science

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Besides the philosophy of science there is a philosophy of particular sciences. This paper addresses each of the classical branches of philosophy (metaphysics, epistemology, ethics, politics and aesthetics) from a soil science perspective. By comparing soil with rock, regolith, biomantle and duricrust we understand it from different perspectives. The roots of soil science lie in the study of soil for its own sake. Logically the main branches of soil science should be physics, chemistry (including mineralogy) and genesis, with each having applied divisions as appropriate: edaphology (agriculture, forestry, ecology); informatics (classification, spatiation, databases); environmental management (conservation, pollution, restoration) and engineering (construction, tillage, mining, traffic and water). Some hybrid subjects such as soil biology belong less in soil science than in the partner discipline. Certain fashionable terms used in soil science have pitfalls. Notable examples (with respective pitfalls) are soil health (condition and quality are sufficient terms); ecosystem services (property, process and function are adequate terms); intrinsic value (no such thing - value is relational by definition); holism and complexity theory (cognitive significance is lacking); sustainability (green politics buzzword); and organic production (a term widely abused). Cognitive significance is crucial. Research funding and public policy interact. Researchers often have a vested interest in accepting and promoting ideas. This applies to recipients of both government and big business funding. Some of the best discoveries result from amateur interest. Professional registration is claimed to ensure ethical practice but could be seen as unethical by those whom it excludes and those who feel they pay excessively for the service. Certification should be voluntary and non-registered practitioners free to establish and benefit from their own reputations. Soil and land can be viewed from an individualist (voluntary) or collectivist (coercive) perspective. Should soil pollution and erosion be tackled by legislation or jurisprudence? Soil profiles are beautiful. The colour and tilth of a ploughed field can be fine things to behold. Restoration after mining entails aesthetic landscaping. Some creative art is soil based. Soil themes in literature can be inspiring. The philosophy of soil science affects the self esteem of practitioners and makes soil science more durable as a discipline.

Soil-vegetation performance of a vegetated engineered cover system associated with mine waste disposal

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Hazardous wastes from mining operations and mineral processing pose substantial environmental and public health risks. A key strategy to minimize these risks involves the use of vegetated engineered covers based on water balance principles. Engineered covers are artificially constructed ecosystems designed to minimize deep drainage into buried hazardous wastes by enhancing soil moisture storage in the top layers, and subsequent water loss through evapotranspiration. On such systems, vegetation water use directly contributes to cover hydrology, and conversely, cover hydrology influences vegetation water use and plant physiology. Material hydraulic properties, atmospheric drivers and vegetation characteristics particularly root distribution and leaf area index are fundamental factors influencing vegetation water use and cover hydrology. Yet until now, a systems understanding of the ecohydrology of covers based on empirical data has been lacking. To address this knowledge gap, we conducted a field study to investigate material hydraulic properties, root distribution, leaf area index and vegetation water use on a vegetated sandy cover system in a seasonally dry environment in Western Australia. The cover material had low moisture retention characterized by rapid wetting and drying. Spatial analysis of hydraulic properties showed very high saturated hydraulic conductivity (38.6 - 79.9 m day^{-1}) exceeding that of natural soils by several orders of magnitude. Compared to mature Mediterranean woody ecosystems, the cover had a low leaf area index (1.4 m^2 m^{-2}) and a superficial root system (maximum rooting depth: 1.5 m). Fine roots showed high spatial variability (coefficient of variation: 50-236%), with approximately 90% of the roots occurring in the top 40-cm depth. Together with atmospheric drivers, these system properties strongly influenced plant physiology and vegetation water use. Upscaling of sap flow measurements showed that annual vegetation water use was quite low (147 mm), accounting for only 22% of the annual total rainfall (673 mm), which was at least three times lower than values (70-90%) reported for natural woody ecosystems. Overall, the findings emphasize the need for a quantitative understanding of material properties, vegetation characteristics, atmospheric drivers and vegetation water use when designing artificial ecosystems to achieve specific hydrological functions.

How can we increase nutrient storage and retention in sands?

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Low nutrient retention and storage is a feature of coarse textured soils including most sands. Increasing nutrient retention in sands requires an increase in the specific surface area of soil through the addition of charged particles with a high surface area (e.g. organic matter and clay). In a series of studies the likely changes in cation exchange capacity (CEC) resulting from the addition of organic materials and clay were investigated on the south coast of WA.

Field surveys investigated differences in organic matter with long term annual and perennial grasses on deep and shallow sandplain soils. Results from this showed little difference in organic carbon contents within the 0 – 30 cm layer. Modelled changes in organic matter suggest the maximum change in CEC is no more than 2 - 3 CEC after 40 years of permanent pasture. Given the long time lag associated with permanent pastures, other forms of organic matter including biochar and compost applied at 5 t/ha were investigated. While the changes in organic matter and CEC were minimal, both biochar and compost resulted in significant yield increases in the year they were applied presumably due to nutrient additions (P, Zn, K, S) associated with these organic products.

In a long term claying trial which included treatments of 0, 50, 100, 200 and 300 t /ha of kaolinite rich subsoil, clay addition result in significant increases in CEC. The addition of 300 t/ha of 30 % clay resulted in an increase in CEC of 1.7 me/100g. Significant increases in nutrients (K and S) were also found. The benefits from claying were immediate and significant yield increases have persisted.

The results from this work show that increasing CEC can be achieved through organic and clay additions. However, the changes are relatively small and require either extensive periods of time or expense to adopt. Further work is required to determine whether the resultant changes in CEC result in biologically and economically significant increases in retained nutrients.

Transformations of soil materials under semi-arid conditions in valley floors in S.W. Australia

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The south west of Western Australia is characterised by an ancient deeply weathered landscape of low relief formed under humid conditions and which is now experiencing a semi-arid climate. The region is largely underlain by Archaean granitic and gneissic rocks that have been altered to deep laterite profiles that are now highly dissected by erosion. The main weathering products are kaolinite and iron oxides. However carbonates, gypsum and other evaporite minerals are now present in the regolith, having accumulated from ground waters in valley floors under the current climate. Valley floors contain diverse arrangements of alluvium, colluvium and residual lateritic regolith together with evaporite deposits. Most regolith materials show evidence of alteration by solute-rich groundwater under the semi-arid conditions that have existed in the region for the past million years. Although kaolinite is the dominant clay mineral; in some cases these sediments have been replaced or impregnated by calcite and dolomite with illite, palygorskite or smectite now being dominant clay minerals in a dolomite matrix. Scanning electron microscopy with EDS of thin sections enables mineralogically distinct materials to be identified and delineated enabling recognition of the types and episodes of alteration. Some valley floor regolith remains dominated by kaolinite with very little variation in matrix material. For these materials, poorly sorted angular quartz and feldspar suggest limited transport of saprolite material with little subsequent alteration. However goethite and hematite have precipitated at redox fronts or texture boundaries throughout the matrix. Often matrix material is a mixture of clay minerals; commonly kaolinite, smectite and illite with relic peds of pure kaolinite persisting within the mixed clay mineral matrix, similarly clay peds persist in some calcareous regolith. This paper considers possible sequences of conditions and events in this landscape as evidenced by soil morphology and mineralogy.

Bulk density sampling requirements for estimating soil carbon stocks: How best to reduce sampling effort?

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Soil organic carbon (SOC) estimation requires bulk density (BD) measurements. BD accuracy contributes to SOC stock uncertainty, in turn impacting how large a change in stock can be detected through time or space. However, BD is difficult and time consuming to collect, and in the Western Australian wheatbelt is further complicated by extremely dry field conditions, coarse-textured soils, and high gravel content. Two alternatives to reduce BD sampling effort are to take fewer manual BD samples at a site (i.e. volumetric rings or clod), or to use more efficient methods (i.e. gamma-neutron density meter). We evaluate these options in the context of a SOC stock survey in agricultural land in Western Australia. Five 25m x 25m monitoring sites in the wheatbelt were intensively sampled for SOC and BD (25 samples at 4 depths: 0-5, 5-10, 10-20, 20-30 cm); BD was measured using direct and indirect methods, namely volumetric ring and clod techniques as well as a gamma-neutron density meter (NDM). Monte Carlo methods were used to explore a range of sampling scenarios, and statistical differences were evaluated assuming non-normal distributions.

The within site BD values measured with conventional and NDM methods were statistically different with large sample sizes (0.05 level using Kruskal Wallis); the measurements diverged further where the coarse fraction volume was greater than 20%. However, SOC stocks calculated from the two types of BD measurements were identical, reflecting the much larger relative variability in soil carbon content. BDs measured with NDM can be used interchangeably with conventional BD methods in the context of SOC stocks. The minimum detectable difference in SOC stock for these five sites varied from 1.2 to 11.5 t C ha^{-1}. Given the maximum SOC stock variability measured and published rates of turnover, SOC stock changes in Western Australia should be monitored on a decadal scale.

Effect of minimum tillage and residue on lentil (*Lens culinaris* Medik.) growth and soil physical properties in an alluvial soil, Bangladesh

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Minimum tillage systems are under development in rice-based cropping systems in Bangladesh but there is still limited understanding of crop performance and soil properties in these systems. The aim of the present study was to determine the effect of strip tillage, bed planting and conventional tillage with the levels of residue retention (20 or 50 % of previous rice crop stubble) on the soil physical properties; the root growth and yield of lentil in the cool-dry season in an alluvial soil. The field experiment was conducted in a farmer's paddy field at Durgapur sub-district, Bangladesh during 2010-11 with tillage systems assigned in the main plots and crop residues in the sub-plots. The present paper focuses on some soil physical properties and the root growth measured at pre-flowering stage of lentil. Bulk density at 10 to 15 cm depth was lower in bed planting than other tillage methods while it was consistently lower in bed planting with 50 % crop residue than other treatments. Similarly, soil resistance was lower in bed planting systems. Soil water at 0-5 and 5-10 cm depth were lower in bed planting than other tillage methods. Under all tillage types very high soil resistance was determined below 10 cm, corresponding to the plough pan created for rice cultivation. Root growth were highest in bed planting, with 50 % crop residue retention, while those under conventional tillage with 20 % crop residues tended to be lowest. However, shoot dry weight, root dry weight, and nodulation were not affected by either tillage or crop residue level. With 20 % rice crop residue retained, bed planting depressed seed yield by 22-27 % while strip tillage and conventional sowing produced similar yields at 1.8-1.9 t/ha. Increasing rice crop residue retention to 50 % only increased yield on beds. While lower surface soil water storage under beds may account for reduced yield, the improved root growth under bed planting produced no improvement in lentil shoot growth or seed yield. The effects of tillage and residue retention on soil properties in the post-flowering growth phase warrant further investigation.

Allocation into soil organic matter fractions of ^{14}C fixed by kikuyu pasture in Western Australia

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This study is part of a project designed to quantify carbon inputs to soils under perennial grass pasture systems. A pulse labelling technique with ^{14}C labelled CO_2 was used to assess the proportion of photosynthate transported below-ground i.e. allocation to roots and various carbon pools in the soil. The field experiment was undertaken on an eleven year old Kikuyu pasture (*Pennisetum clandestinum*) in the south west of WA. ^{14}C labelled CO_2 was introduced into chambers above microplots contained within metal cylinders driven into the ground. Plants were labelled in active growing phases during late spring, summer and autumn following a simulated grazing. At intervals of 1 week, 6 weeks and 1 year following labelling, shoots were harvested and the microplots were destructively sampled in layers down to 70cm. Soil was air dried and then passed through a 2 mm sieve to remove gravel and recover 'coarse' root material and other plant residues. Subsamples of soil were wet-sieved to separate organic matter between the particulate fraction (>50 um <2 mm) and humus fraction (<50 um). Each soil fraction was finely ground before the total C content and ^{14}C content was measured. Shoots and coarse roots were also finely ground. Root, shoot, particulate soil organic matter and humus were each combusted in a Roboprep CN analyser, with CO_2 trapped in alkali for the analysis of total C and in scintillation cocktail for $^{14}CO_2$ determination. The paper will outline the allocation of C under kikuyu pasture and quantify C turnover between the soil organic fractions. This information will be used to assess the capacity of perennial grass pastures to sequester carbon below ground.

Potassium use efficiency by wheat and barley grown in grey sand with saline or non-saline conditions

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Currently over 1 million hectares in the south-west agricultural area are severely affected by salinity, and there is increasing incidence of potassium (K) deficiency. Leaching of K especially in sandy soils is also a significant contributor to poor K-use efficiency in cropping system. We conducted two glasshouse experiments to investigate K-use efficiency by wheat and barley grown in grey sand with non-saline or saline conditions. In experiment one, plants were supplied with 15, 22.5, 30, 45, 75, 135 mg K kg^{-1} under non-saline conditions and grown to maturity. Shoot and root dry weights reached a plateau at 75 mg K kg^{-1} at most growth stages. Reduced shoot growth by K deficiency was best explained by reduced tiller numbers and the rate of development. Luxury K supply (135 mg kg^{-1}) greatly increased shoot K percentage compared with adequate K supply (75 mg kg^{-1}), but both treatments had similar seed K and N percentages and harvest index. Seeds were not properly filled under severe K deficiency, and had decreased seed size (13–18 mg) at moderate K deficiency, compared with 30 mg at adequate or luxury K supply. With K deficiency the shoot:root ratio increased. The greater effect of K deficiency on root growth may make low-K plants more vulnerable to drought conditions. In experiment two, plants were first supplied with 30 mg K kg^{-1} for 4 weeks to create moderately K-deficient plants, and then subjected to varying Na and K levels for 3 weeks with measurements of K and Na uptake, K substitution by Na and plant growth. Although high Na (300 mg Na kg^{-1}) reduced leaf numbers, applying moderate Na (100 mg Na kg^{-1}) to the K-deficient plants stimulated leaf development in barley cultivars. It also significantly increased tillers and shoot biomass, together with shoot Na accumulation, in the salt-tolerant CM-72. Root growth, relative to shoot growth, was enhanced by adequate K (75 mg K kg^{-1}) versus deficient K, but not by moderate Na. The substitution of K by Na was influenced by soil K and Na status and also the potential for Na uptake by the plant which seemed to be related to the salt tolerance of cultivars. The failure of moderate Na to stimulate root growth under K deficiency may expose the salt tolerant plants to greater water stress. Both experiments illustrate the potential importance of K nutrition to minimising water stress in cereals, but further testing of this proposition is needed in the field.

Isotopic image analysis of soil-microbe-root interactions at the nano-scale

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Many microbially-mediated processes exhibit high spatial variability across a wide range of scales (nm to cm) and very little is known about the spatial organization of soil microorganisms and its control. Understanding the link between the heterogeneity of the soil's physical/chemical environment and its impact on biological processes is arguably the next major frontier in soil science. Nano-scale secondary ion mass spectrometry (NanoSIMS) is a novel imaging approach that links isotopic analysis at high sensitivity with high resolution microscopy; levels of spatial analytical resolution are better than 50 nm. Here we have used NanoSIMS for soil-microbe-plant studies to trace and image ^{15}N isotopes into individual bacterial cells and intracellular within root cells.

Amino acids are an important source of N for plants and microorganisms and are a major factor regulating ecosystem productivity. ^{15}N- and ^{13}C-labelled amino acids are often used to determine the relative competition between plants and microorganisms for dissolved organic N. However, it remains challenging to distinguish between direct and indirect (amino acids first mineralized to NH_4^+) uptake by roots. Existing methods also lack adequate sensitivity for data collection at appropriate spatial scales. In this study we combined traditional ^{15}N isotopic tracer techniques with NanoSIMS $^{15}N/^{14}N$ imaging approaches to investigate the competition between roots and microorganisms for amino acids in the rhizosphere. Highly enriched ^{15}N-labelled solutions containing N as either NH_4 or amino acid were injected along the zone of root elongation of Wheat (*Triticum aestivum L.*). Data indicate differential enrichment of roots cell types and microbes and show clear spatial patterns between the soil physical matrix (assessed as ^{28}Si), soil organic matter (assessed as ^{12}C), microbial cells-^{15}N and plant roots-^{15}N within the rhizocosm. NanoSIMS enabled visualization and quantification of nutrient resource capture between competing plant and microbial cells. The ability to measure ^{15}N enrichment within the rhizosphere at this previously unattainable scale provides the first opportunity to simultaneously quantify and image nutrient flow pathways in complex biological systems at a scale appropriate to the size of the competing organisms.

Does biochar application increase retention and availability of phosphorus to wheat under leaching conditions?

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Phosphorus (P) fertilizers have long been applied to Western Australian (WA) soils to enhance food production and are critical for ensuring global food security. However, due to high levels of P (*ca* 50 kg/ha P) being applied, leaching is experienced on coarse-textured soils. Leaching of fertilizers not only decreases nutrient availability, but can also cause algal blooms, thus polluting water bodies. Strategies are required to minimize P leaching while still enabling sufficient P availability to crops. We hypothesized that biochar addition to soil would increase arbuscular mycorrhizal fungal (AMF) colonization of wheat roots, decrease P leaching and increase plant P uptake. A glasshouse lysimeter leaching experiment was conducted to assess these hypotheses on wheat (*Triticum aestivum* L. var.Wyalkatchem). A factorial randomized block experiment was designed where two types of biochar (chicken manure; CM and wheat chaff; WC) with rates of (0, 10 and 20 t/ha) and three P fertilizer application with rates of (0, 25 and 50 kg/ha) were applied to a coarse-textured soil. Leaching events were conducted over a period of 8 weeks at 2 weeks interval. Biochar application to soil increased AMF colonisation (up to 70%) of wheat roots at low rates of fertilizer P and subsequently declined at the P application rate of 50 kg/ha to about 35%. P leaching was increased with biochar application probably due to the high amount of P fertilizer applied and P in biochar. P uptake in plant was significantly increased ($p<0.05$) by biochar application and also differed between 2 biochat types. We conclude that the high levels of applied P from fertilizer and biochar enhanced leaching even though P uptake increased. Studies using low levels of fertilizer P warrant further investigation.

Salt-affected soils of south-west Australia: Implications for deep drainage

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Dryland salinity has spread to cover one million hectares in southwest Australia, and while the levels of salinity and their implications for agricultural production have been thoroughly examined, relatively little is known about the characteristics of the salinised soils. Naturally-occurring saline soils exist in this region, but because those soils were of limited interest for agriculture, little research has explored their characteristics either. Strategies to rehabilitate salinised soils, such as deep drainage, need to be guided by a detailed understanding of their properties and their likely response to treatments.

Detailed incremental soil analysis was undertaken on profiles (0-1.45 m depth) at five sites adjacent to deep drains in the following locations of Western Australia: Beynon Rd, Beacon, Morawa, Pithara and Wallatin Creek. The soils vary in salinity levels, pH, texture, and exchangeable cations. Most saline soils at Beynon Rd, Morawa and Wallatin Creek had EC (1:5 water extract) > 200 mS/m, but the Beacon soil was only marginally saline (45 mS/m) at the surface. In general, profiles are alkaline to strongly alkaline in the sub-soil, however, moderately acid topsoil pH occurs at two of these sites. All soils were sodic to strongly sodic in the sub-soil and sodic in topsoil also. Exchangeable Mg levels were similar to or greater than exchangeable Ca. All soils had low organic C levels (<1 %) with the lowest being 0.3 % in Pithara and Beacon soils. Kaolinite and or halloysite were the major minerals present at these sites. Surface layers at most of these sites had more than 70 % sand, except at Wallatin Creek, whereas clay content varied between 14 and 23 % in surface layers. In this paper, we discuss the properties of the salinised soils in relation to those of naturally-occurring saline and sodic soils of southwest Australia, and the prospects of recovery of soil productivity following deep drainage. The responses in productivity of salinised soils to lowering of watertables are expected to vary with the salt levels in the soil, rainfall, soil texture, soil structure, sodicity and site vegetation cover.

The application of cattle manure to improve soil fertility for crop production in Uganda

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Declining per capita food production and soil fertility depletion are threatening the livelihoods of many small-holder farmers in East Africa, including Uganda. High demand for food due to the increase in population has necessitated the need to improve crop yields where synthetically manufactured fertiliser use in the production system is often scarce and expensive. Cattle manure provides essential plant nutrients (mainly nitrogen, phosphorous and potassium) and is available locally; however, there is little information in Uganda on soil fertility status, the most effective rates of cattle manure, methods of application, crop requirements for specific nutrients and limiting factors to crop production. A survey was conducted on selected small-holder farmers in Uganda, in the central districts (Kampala and Wakiso) in January 2010 to identify socio-economic factors influencing the use of fertiliser and the current level of soil fertility as constraints that were most limiting to plant production. It was apparent from the survey and soil sampling that soil physicochemical values varied greatly amongst the soils and sites investigated. Unfortunately, in many situations the application of fertilisers being used didn't target specific nutrients most limiting to crop production. The main findings from the soil survey will be presented in this paper and subsequent field research and nitrogen modelling that has been conducted to better assist farmers in Uganda improve crop productivity through more effective fertiliser practice.

Archaeal ammonia oxidisers are widespread throughout southern Australian agricultural soils

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The recent discovery of ammonia oxidising capacity within the Archaea (AOA) challenges the assumption that nitrification in soil is chiefly the domain of ammonia oxidising bacteria (AOB). AOA appear to be favoured by a set of environmental conditions which are common in some Australian agricultural soils, specifically low pH, low NH_4^+ content and low organic carbon content. The aim of this study was to survey a range of soils from across the cropping zones of Western Australia and South Australia to assess the abundance of AOA relative to AOB and to begin exploring environmental factors which may impact upon their distribution. Samples were collected from 45 sites across the Western Australian wheatbelt and South Australian agricultural zone. Soils were tested for pH, NH_4^+/NO_3^-, organic carbon, carbon to nitrogen ratio, potential nitrification rate, electrical conductivity and DNA content. Climate data for the year of collection was downloaded from the SILO website. AOA and AOB abundance were measured using real time PCR quantification of the genes encoding the A subunit of the ammonia monooxygenase enzyme (*amoA*). Multivariate statistical analysis was applied to look for correlations between soil properties and abundances of AOA or AOB. AOA were present in the majority samples but overall numbers and ratios to AOB varied considerably. Multivariate analysis shows that AOA abundance was linked to climate, soil texture, and NO_3- content. AOB abundance was linked to climate, and soil texture. Location was also an important factor in determining ammonia oxidiser community structure. Interestingly, potential nitrification rates were not linked to either AOA or AOB abundance but were strongly linked to organic carbon and total nitrogen contents and weakly with soil pH. This study shows that AOA are widespread in Western Australian and South Australian soils and they, along with AOB, appear to be significant contributors to the potential nitrification rate in many of these soils.

Lucid Phoenix: An interactive pathway key to identify Western Australian soils

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Lucid Phoenix is a computer based program that plays interactive dichotomous identification keys. The program Builder and Player that enables traditional paper based identification keys to be published on the Internet and/or CD. There are several traditional ways of writing interactive pathway keys, but all have the same basic structure and easy to build. This pathway key can be used as an electronic identification or diagnostic tool. Lucid Phoenix uses the latest cross platform technology, allowing Phoenix keys to be directly embedded within web pages and can operate on a variety of platforms, including Microsoft Windows and Macintosh. A Phoenix key can be thought of as a tree-like arrangement of questions and providing a simple point-and-click interactive interface. When you have made a choice, Phoenix player will do three things. It will: (i) write your answer to that step in the History panel (ii) move some entities from Entities Remaining panel to Entities Discarded panel and (iii) display the next question of the key in the Questions panel. Depending on the answers given to the questions at each branch point, a user of a Phoenix key follows a path through the key, eventually arriving at an answer (an entity or taxons in the key). Lucid Phoenix interactive pathway key allows allocation of soil profiles to the Super group or Subgroup levels within the Western Australian soil classification. The interactive method makes reliable allocation of soils to classes in the Western Australian soil classification more accessible for individuals without specialist knowledge. Use of the interactive pathway key quickly provides users with an understanding of the Western Australian soil groups. The interactive key includes access to a digital version of the Western Australian soil group factsheet.

Low sulfur, potentially acidic soils and sediments on the Bassendean dune system, Perth, Western Australia

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Rapid urbanisation in Perth metropolitan areas coupled with a decline in rainfall below the long term average has lowered the water table levels to an extent that exposed sulfidic sediments to oxidation and consequently acidification of ground and surface water in the Bassendean Dune System. The highly weathered soils and sediments of this system contain a very small percentage of pyrite, and although their inorganic sulfur (S) levels are low (commonly below trigger values for mitigation action of 0.03 %) their acid generating potential is unexpectedly high. This study focuses on assessing the leachate characteristics of six intact soil cores with low inorganic S values (<0.03%) and potentially-acidic character (pH_{FOX} 2- 3). The experiment included five more columns (control): two from a site with low S levels (<0.03%) and non-acidic character (pH_{FOX} >3) and three from a site with high S levels (0.2%, pH_{FOX} <2: intact, mixed and lime-treated, respectively). During a course of five months of oxidation and five cycles of saturation and drainage, the pH of leachate of the non-acidic columns remained stable at 6.5, while the pH of the leachate from the soil column with pH_{FOX}= 3-4 remained stable at 4.5. By contrast, the pH of leachates from five other low inorganic S columns, dropped from *in situ* 7- 8 to 2- 3 during the period of 30 to 60 days after initial drainage, while their redox potential, titratable acidity levels and the concentrations of dissolved metals increased significantly, and their colour changed from natural brown or yellow to bright yellow/ orange/ colourless. The pH of leachate from the lime-treated (high inorganic S content) column remained stable at 8.3 from *in situ* 7.5. It is concluded that sands from various sites within the Bassendean Dune System with low S levels, commonly 0.002- 0.005% S, have typical coastal acid sulfate soil characteristics if drained or disturbed by earthworks. The low pH (~3) created by the oxidation of sulfides in these materials leads to release of dissolved aluminium, iron, nickel, uranium and chromium in environmentally toxic concentrations. Therefore the present S trigger values for the identification of potentially acid sulfate soils, used on the Bassendean Dune Systems should be questioned, re-assessed and ultimately lowered. Also other identification methods such as pH_F/ pH_{FOX} should be given more emphasis, when deciding upon disturbance of low S sands.

Characteristics of pyritic sandy podosols in wetlands on the Swan Coastal Plain, Western Australia

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Potential acid sulphate soils (PASS) in and adjacent to wetlands in swale sites within the Bassendean Dunes are a major issue for urban development on the Swan Coastal Plain. These soils have the potential to become actual acid sulphate soils (AASS) unless the watertable is maintained at a suitable level to prevent the oxidation of acid generating minerals. When the oxidized sulfur compounds produce more acidity than the acid-neutralizing capacity of the soil pH decreases below 4 with considerable damage to infrastructure and biota. This research investigated 41 sandy podosols (186 samples) including A, E, B, coffee rock, mud, peat and C horizons from swale locations in the Bassendean Dune System, Tamala Limestone and Guildford Formations. Acid sulphate soils in the Bassendean Sands are characterised by dark brown and pale leached sand which contains very little clay and no carbonate and is thus unable to buffer reductions in pH. Some profiles contain buried soils (Palaeopodosols) representing former levels of the water table. Electron microscopy with EDS/SAD and synchrotron XRD provide unambiguous evidence for the occurrence of pyrite, elemental sulfur and rarely marcasite and jarosite in these sandy podosols. Two pyrite morphologies are present: discrete submicron single crystals (≤ 1 μm) and 10-20 μm framboids. Minor buffering of acidity is provided by organic matter, allophane $(Al, Fe)_2O_3(SiO_2)1.3\text{-}2(H_2O)_{2.5\text{-}3}$), kaolin, gibbsite and Fe-oxides which have high surface area with exposed hydroxyl. Electron microscopy is an excellent technique for detecting minor amounts of acid producing minerals and to determine the size, shape, and composition of nanometric S-minerals but this technique is very expensive and time consuming. The grain size distribution and grain morphology of pyrite determines the reactive pyrite surface area which affects oxidation rate and thus the required management of engineering and groundwater developments on these soils. Oxidation of pyrite in soil with hydrogen peroxide is a commonly used and highly effective technique for determining the potential environmental risk of acid sulfate soils (pHFOX<2.5).

Under zero-tillage, soil water content is poorly related to soil water repellency

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In southern and western Australia more than 5 million hectares of farmed land is water repellent. The majority of these soils are sandy and therefore highly susceptible to erosion. This has led to the adoption of practices such as minimum tillage and stubble retention. However, retention of stubbles can lead to increases in soil organic matter and consequently increased soil water repellency. A group of farmers on the south coast of Western Australia observed that in a system with stubble retention and zero-tillage (with the minimum of disturbance) the expression of water repellency ‘disappeared’. In a 3-year study on these sandy soils, water infiltration and water repellency, soil C and crop performance were monitored in treatments comparing zero-tillage vs cultivation and stubble retention vs stubble removal (by burning or grazing). Stubble retention and zero-tillage promoted higher levels of soil C than cultivation and stubble removal. As expected, in soil samples collected from each treatment, soil water repellency (as measured by the Molarity of Ethanol Drop (MED) method) followed a similar pattern to soil C with the worst repellency under zero-tillage and stubble retention and least under stubble removal and cultivation (R^2 (%C vs MED) ranged from 0.75-0.83). However, soil water content measured in the field using a hand held time domain reflectometer (TDR) contradicted the findings on water repellency and indicated that water infiltration was best under zero-tillage and stubble retention and poorest under stubble removal and cultivation, and this impacted on crop performance. The results suggest that mechanisms other than just soil water repellency are involved. It is hypothesised that under zero-tillage, bio-pores formed by roots and small animals are preserved and provide pathways for water movement in the soil. These findings challenge traditional thinking on soil water repellency and potentially have implications for crop management.

Soil organic carbon for soil condition – The south coast soil carbon pilot project

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Soil organic matter is best approximated from a measure of soil total organic carbon (TOC), the concentration of which is influenced by climate, land use, fertility, tillage and stubble management. The purpose of this project was to better inform the South Coast community of; current soil organic carbon densities at sites believed most likely to sequester organic carbon, the current potential to sequester soil organic carbon at these sites, the appropriate and emerging methods to quantify soil organic carbon, and the strong inter-dependence between soil organic carbon and soil condition. At each of ten benchmark site the mass of TOC (0-1m) and labile organic carbon (LOC, 0-0.3m)) were quantified, and projections of future trends in TOC under three scenarios were modeled. All soil layers were analysed for pH, electrical conductivity and clay content, the latter being an important input for the prediction of TOC trends in the top-soil. TOC within the soil profile (0-1 m) ranged from 32.5 to 155.5 t/ha with on average 73% residing in the top-soil. TOC in the top-soils ranged from 24 to 115 t/ha (equivalent to concentrations of 0.87 to 3.34%), with on average 51% (ranging from 20 to 74%) being in the labile carbon form. LOC was only modestly correlated with TOC, and the future trends of this labile carbon in relation to land management are of considerable interest. Spatial variability within the plots was very high across all soil layers for both TOC and LOC and demonstrates the great difficulty in quantifying organic carbon at the paddock scale, let alone estimating changes in TOC in the short-term. There is great potential to increase TOC across the WA south-coast if biomass production ,with substantial residue retention, can be increased. Such a biomass increase is to be expected from well managed perennial pastures, but may also be realised under cropping and annual pastures if sub-soil constraints, which are known to be quite extensive, can be overcome.

The nutrient story on the Palusplain – Is there a role for smart soils?

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The Palusplain near Mandurah contributes significant quantities of nutrients into the Peel Harvey River and estuary systems. Whilst there have been many years of research and extension, challenges remain to better understand nutrient pathways and identify ways to sustain this fragile environment.

The Palusplain is a seasonally waterlogged flat wetland east of the Swan Coastal Plain. The soils are generally alluvial deposits overlain by highly leached sands with over 60% of the area comprising coarse sandy surfaces over impermeable layers of ironstone or clay. There are 44,500 ha with 70 to 100% of that area having characteristics predisposed to high to extreme phosphorus (P) export hazard.

Prior to European settlement the land was heavily vegetated. Settlement brought agriculture and inundation leading to extensive drainage works. Nutrients have leached or runoff the land and water quality has declined in the waterways with resulting algal blooms. The quantity and pathways of nutrient loss from the soils are affected by proximity to water bodies, water logging, nutrients applications, soil characteristics and management practices. Agriculture is a major contributor of nutrients, 45% in the Peel Inlet and 40% in the Harvey Estuarine System. On a per hectare basis, the highest P inputs occur in piggeries, annual horticulture, dairies and urban residential land, whilst nutrient input rates into beef grazing are comparatively low but represent the largest P input into the Peel Harvey system, despite its low unit area P input. The current urban inputs are higher than beef grazing and replacement of beef grazing land with urban land may result in degradation of water quality if there is little opportunity for nutrients to be tied-up or retained in the drainage system.

This presentation describes the soils, nutrient pathways, measures that have been taken to reduce nutrient export, potential remedial measures including soil amendments and information gaps for low nutrient loss agriculture and urban land uses. Could engineered soils – Smart Soils, be part of the solution to eutrophication of the Peel-Harvey catchment and estuary?

From tailings to soil: Processes and thresholds controlling pedogenesis in bauxite residue (‘red mud’) deposits

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‘Cap and store’ approaches to tailings management are increasingly being replaced by *in situ* remediation and rehabilitation initiatives. *In situ* remediation involves changing tailings properties (*e.g.* pH, EC) from very low (pH 1-3) or very high (pH 9-13, EC >4 mS/cm) values to plant-tolerable values, by way of applied treatments and weathering. Because the objective of *in situ* remediation is to achieve a sustainable plant cover, pedogenesis is implicit in the modification of tailings properties. Identification of processes and thresholds controlling soil formation on tailings deposits is essential to achieving rapid *in situ* remediation and establishment of plant cover. In the case of bauxite residue, the major barriers to plant growth are the high pH and salinity of fresh residue, followed by lack of biological activity and organic matter, as well as available plant macro- and micronutrients.

Four bauxite residue field sites (Linden, Guyana; Corpus Christi, Texas; Bauxite, Arkansas; and Sao Luis, Brazil) were sampled to investigate the potential influence of initial residue properties, age, applied treatments (*e.g.* sewage sludge, pyritic mine spoil, green waste), and climate upon the weathering trajectories and pedogenetic processes occurring within the residue deposits. Chemical (pH, EC, titratable alkalinity, extractable plant nutrients, total elements), mineralogical (XRD, amorphous Fe/Al/Si/Mn oxides) and physical (particle size) analyses were performed to evaluate the extent of soil formation under the various treatments at each site.

Removal of soluble salts by rainfall (or irrigation) leaching appears to be the primary barrier to revegetation. Once salinity reaches a plant-tolerable threshold, further leaching combined with exudation of carbon dioxide/organic acids from plant roots appears to accelerate the decrease of pH in bauxite residue. Attempts to establish plant cover by fertilising and seeding should therefore be delayed until a plant-tolerable level of salinity has been achieved within the rooting zone, through rainfall leaching or irrigation. The influence of vegetation, climate, and applied treatments upon dissolution of alkalinity-generating minerals such as sodalite and calcite are also discussed. Finally, accumulation of plant nutrients and organic matter are discussed and recommendations given for achieving satisfactory and rapid *in situ* remediation within bauxite residue deposits.

Towards a national soil policy – Are we making progress?

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In 2007 the National Committee on Soil and Terrain commissioned the preparation of a policy discussion paper on the state of soil policy and soil management in Australia. The paper - *"Managing Australia's Soils: A policy discussion paper"* - was prepared by Andrew Campbell and published in 2008 . It was subsequently circulated for public consultation from which substantial feedback was received. The discussion paper and feedback report are on the ACLEP website (www.clw.csiro.au/aclep/).

As a result of public comment three key areas for national action were identified, including;

- research and development collaboration
- coordination of soils assessment and monitoring information and data
- improved linkages of extension programs.

Progress is being made on all three fronts.

A business case for a national soils cross-sectoral Research, Development and Extension strategy under the National Primary Industries R, D and E Framework (www.daff.gov.au/agriculture-food/innovation/national-primary-industries) is being developed, and likely to be implemented. Such a strategy would mesh with other cross sectoral strategies (climate, water) and provide soils framework for the industry strategies (e.g. grains, wine etc.). Included in this work is a plan for better linkage and coordination of soil extension programs.

The National Committee on Soil and Terrain is reviewing the coordination of soils assessment and monitoring information and data across Australia. Possible outcomes include an improved national soil information system including soil condition and monitoring data, improved public understanding of the importance of soil and "land literacy", standard approaches to the capture, storage, interpretation and communication of soils information and a review of soils legislation across Australia.

Clay addition to lime-amended biosolids: soil amendment with lesser carbon emissions and efficient waste recycling

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Addition of clay to conventional lime-amended biosolids (LAB) to form LaBC® has been proposed as an environmentally safe method for disposal of sewage sludge by the Water Corporation, WA. Ellen Brook catchment in south-western Australia was identified as a potential site for recycling lime amended biosolids when clay was added because more than 200 km^2 of this catchment requires restoration due to non-wetting, coarse-textured soil problems and associated limitations to microbial activity. It was hypothesised that LaBC® application would decrease water repellence and support growth of higher soil microbial biomass than either un-amended soil or soil amended with the clay or lime components of LaBC® or LAB. Increasing rates of application of LaBC® was expected to decrease carbon emissions compared with application of lime-amended biosolids (LAB). LaBC® was applied to soil in couple of incubation experiments at 3 rates (50, 100 and 150 t/ha, wet weight basis) and clay, lime and LAB were added at rate equivalent to their components in LaBC®. LaBC® eliminated water repellence, even at the lowest application rate. In general, treatments without clay did not eliminate water repellence. LaBC® amended soil consistently released much higher CO_2 than did soil amendment with LAB or other treatments when applied at the lowest rate. Application of clay alone suppressed microbial respiration, presumably due to physical protection of organic matter from microbial decomposition. Carbon mineralisation and subsequent CO_2 release was consistently lower than the un-amended soil for the duration of incubation when clay was added. For the highest rate of LaBC®, microbial activity and carbon-mineralisation was consistently less than for LAB, probably because of the increased clay content. Hence, biosolids blended with clay to produce LaBC® could be efficiently recycled and applied at up to 150 t/ha (as LaBC®) in coarse-textured soils to improve the soil quality.

Acid sulfate soils in the Perth metropolitan area

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A broad scale investigation was conducted to map the distribution and extent of potential acid sulfate soils (ASS) in Perth metropolitan region of the Swan Coastal Plain. A total of 200 sites were selected using desktop GIS analysis of wetlands, groundwater contours and soil types. Soil cores for depths to 6 metres were extracted, logged and analysed in the field for pH. Detailed sulfur analysis was undertaken where field pH indicated occurrence of ASS. Acidification potential of limited number sites was also assessed using incubation and column leaching studies.

Bassendean Dune System is the major surface geological formations in the Perth metropolitan region. In the topographic lows of this formation, humus podzol soils with a strongly cemented dark brown, organic B horizon (coffee rock) are common. In the mid slopes and crests, humus podzol and podzol respectively occur. All these soils are sandy, highly leached and consequently poorly buffered.

Evidence of ASS materials was found in over 80% of the investigated sites. Up to 40% sites contained chromium reducible sulphur (SCr) above the ASS criteria (0.03%S) in the top 6 m soil horizon. These sites are mostly in the estuarine sediments and damplands of the Bassendean formation. About 40% of the sites showed zones of soil pH in hydrogen peroxide (pH_{FOX}) <3.0, which indicates occurrence of ASS. The sulphur content of these materials was below the action criteria. A representative of these materials was further investigated in incubation studies to determine if these soils acidify in air strongly enough to pose an environmental risk.

Incubation studies have revealed that these soils materials readily acidify in air to produce soil pH as low as 2.5. According to current policy guidelines disturbance of these soils does not require an ASS management plan as their sulfur content is below the action criteria. Pros and cons of lowering the action in view of this information will be discussed.

Effect of clay amendment of sand on nitrogen, phosphorus and cations in soil solution and in leachate

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Nutrient leaching in sands decreases fertiliser use efficiency and may depress plant production. Application of high cation exchange capacity (CEC) materials (e.g. high activity clay minerals) is hypothesised to reduce nutrient leaching and increase plant nutrient uptake in sands. A column experiment was established to determine nutrient (NH_4^+, NO_3^-, K, Na, Ca, Mg and P) concentrations in soil solution extracted by Rhizon samplers and in leachate from a Badgingarra sand (1.4 % clay) with three soil amendments (nil, clay-rich soil, bentonite clay) and three fertiliser rates (nil, 38 N 18 P 50 K kg ha^{-1} and 76 N 36 P 100 K kg ha^{-1}). Soil amendments were applied at the rate of 50 Mg ha^{-1}. The soil columns were leached with de-ionised water equivalent to 50 mm rainfall every 4 days. Leaching loss of soil solution NH_4^+ was decreased 38-43 % by bentonite addition but little of the soil solution N was in NO_3^- form and bentonite had no effect on leaching of this form of N. The application of bentonite was able to increase NH_4^+ in soil solution of top soil and delay leaching of NH_4^+ by 15 days after fertiliser application. The application of bentonite and clay decreased K leaching by 26-28 %. However, increased amounts of Na and Mg were leached from bentonite-amended sand. The soil solution indicated that there was a decrease and delay in leaching of NH_4^+, and K in clay-amended sand which can be attributed to its cation exchange capacity but may also involve decreases in macropore abundance. By contrast the decrease in P leaching with clay-rich soil addition suggest that this amendment have significant P sorption that was lacking on bentonite. The clay amendments had different effects on nutrient leaching that were related to their mineralogy, effects on solution pH and probably on changes in surface area and pore size distribution.

Biochars influence nitrogen leaching and availability to wheat plants

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There is currently great interest and debate over the potential agronomic benefit of biochar application to soil. However, the effects of biochar on nitrogen (N) dynamics during crop production are limited and require further investigations. Two lysimeter experiments were conducted in glasshouse and field conditions to investigate the effects of biochar on N leaching, retention in soil and availability to wheat crop. First, a glasshouse trial using two fertiliser regimes (water soluble and slow release) was conducted in river sand mixed with jarrah biochar. The experimental design was a randomized block design with 6 replications, two biochar rates (0 and 20 t/ha) in combination with either soluble (NH_4NO_3 @ 100 kg N/ha) or slow release mineral (100 kg N/ha) fertilisers. N contents in leachate, soil and plant were measured. Results indicate that biochar addition did not increase plant growth even though the NO_3 retention in soil increased. Second, a field lysimeter trial was conducted to assess the effects of different levels (0 and 50 kg N/ha) of ^{15}N labeled diammonium phosphate (DAP) with different types (chicken manure and wheat chaff) and rates (2.5 and 7.5) of biochars on N leaching. Lysimeters were filled with surface soil 0-15 cm and then with subsoil from 15-90 cm depth. Leachate was collected after each rainfall or irrigation events. Soil samples were collected at harvest 0-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-60, 60-90 cm depths for monitoring the NO_3 and NH_4 movement in the soil profile. Wheat grain yield and yield components were not significantly affected by biochar type and rate. In general, it was concluded that biochar addition to the soils did not have a significant effect on plant growth even though the N availability to plants increased by reducing N leaching.

Tillage type and its effect on initial seedbed soil water content and crop yields

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Surface soils in the High Barind Tract (HBT) of Bangladesh have silty clay texture (26% silt, 24% clay) and high bulk densities (1.4 to 1.6 g/cm^3). Germination, emergence and early seedling growth of the winter season crops grown on residual soil moisture can be limited in these soils due to rapid drying and hardsetting of the surface soil. The traditional method of sowing post-rainy season crops in this region is broadcasting seed followed by full tillage. Minimum tillage options are now being evaluated and a study was conducted on the following tillage types: strip tillage (rotary blades only directly in front of seed delivering tynes); zero tillage: single pass shallow tillage (full rotary tillage preceding seed delivering tynes); broadcast (power tiller cultivation with broadcast seeding followed by another pass with the power tiller); and a fallow treatment was also included. The chickpea crop was sown at a soil water content considered to be optimum for germination and emergence (26 % v/v). All tillage systems had a decrease in soil water content in the seed furrow (0-6 cm) in the 23 days after sowing. The least overall loss of water was in the broadcast system at 3.3 %. Zero tillage lost the most water in the seed furrow over the period from sowing to emergence, a similar amount of soil water as land kept fallow (8.4 and 8.9 % respectively, 0 to 6 cm depth). Final emergence of chickpea seedlings in the broadcast system was significantly lower than all other systems. This may be due to the variable depth of the seed which may leave some seeds close to the surface, uncovered and exposed to air. In comparison, in the poorly covered zero tillage system the seeds were sown deeper into the furrow, without detriment to final plant establishment. Minimum tillage technology allowed timely planting of chickpea into soils with non-limiting soil water and soil strength to promote seedling emergence and growth. Continued testing of minimum tillage techniques in the HBT is required to match the surface soils conditions at sowing to the tillage type which will provide optimum plant establishment.

Clay deposition in lateral root catchments of eucalypts: construction and biogenetic activity of a phytotarium in a semiarid environment

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In this paper we highlight the role of lateral roots of mallee- and tree-form eucalypts in biogeneration of clayey pavements and calcareous horizons in the contemporary setting of Pleistocene playa lake dunes in southwest Western Australia. The examples described are for York gum at Toolibin, red morrel at Taarblin Lake, and mallees and yate at Lake Chillinup. Morphologies and composition of the precipitates are described and ancillary effects of the eucalypts on profiles are compared to those evident under other types of immediately adjacent vegetation.

Profiles in the lateral rooting catchments of York gum contain a diffuse horizon of rubified clay below a loamy sand and sitting above mildly calcareous sandy clay loam. Profiles under red morrel comprise a pastel-brown loamy sand overlying a diffuse horizon of calcareous clay loam with hard and soft carbonate nodules. Mallees and yate contrast with the above in showing dense consolidated pavements made up by coalescence of discrete columns

Using Chillinup as an experimental site, deep mining of key constituent elements of clay (Al and Fe) and other mineral elements are studied by root xylem sap analysis. Uplifted mineral elements are subsequently delivered to foci of clay formation in specific regions of the lateral root catchments. Microbia at these locations are suspected agents of clay neoformation. Marked mineralisation of profiles in and below pavements are recorded in contrast to the acidic depauperate profiles under adjacent non-eucalypt heath.

Our interpretation of the clay pavement/texture contrast situation for southern Australian eucalypt ecosystems is that it comprises one of a number of bioengineering activities underpinning soil-forming processes across semiarid ecosystems. Activities of this kind are mostly spearheaded by deep-rooted tree and shrub species and we use the term ‘phytotarium’ to collectively define the macro players and key microbial agents involved in pedogenic processes.

First steps in overcoming a P addiction

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Soil testing programs over the last 25 years suggest P levels in many soils in Western Australia (WA) are above the maximum recommended for a response to P in pasture growth. This represents an economic burden, and an environmental risk to water quality. It suggests inefficient use of P inputs, and a less than ideal economic outcome for landholders where attention is not paid to soil testing and fertilisation decisions are not in line with the results of that testing. A project associated with WA's Fertiliser Partnership aims to take the first steps to improve P management using a voluntary approach to achieve better fertiliser management outcomes. The project recognises that a stepped approach is required. The first step to reduce current high soil test P levels to agronomic targets. The project targets the beef grazing industry in sensitive coastal catchments where water quality problems are at their greatest. It aims to improve fertiliser management through the use of whole farm soil testing and nutrient mapping assessed against a set of agreed industry soil test standards. The standards recognise the significance of both soil P and soil pH. Recent increases in input costs mean that economic outcomes are more easily demonstrated. The project uses tools including Soil Productivity And Nutrient Assistant – SPANA, colour coded farm nutrient maps, and interaction with FertCare accredited advisors to empower farmers to undertake soil testing as a standard part of business practice. Soil test data collected as part of the project reinforces evidence collected over the last 25 years that there is room for improved nutrient management. The data up to and including 2011 shows that 66% of soil samples have high P status when assessed against the 95% maximum production (P95) level, increasing to 89% when referenced against the 80% maximum production (P80) level. Seventy eight percent of samples have pH < 5.5, while 50% have high P95 and low pH and 10% have high P95, low pH, low potassium and low sulphur. The overall nutrient status in the sampled catchments indicates that there is significant opportunity to improve nutrient management on the sampled properties.

Build-up of available phosphorus beyond critical values in WA soils calls for a more profitable and greener practice

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Recent volatility and increases in the price of phosphorus (P) fertilises and concerns about potential off-site environmental impact of this non-renewable resource suggest the need to assess the efficiency with which it is used. We aimed to determine the (1) P balance efficiency (PBE is percentage of applied P recovered in harvested products) of crops and pastures at paddock and farm scales, (2) effect of P balance and soil properties on the pattern of available P build-up and (3) current P and fertility status of WA agricultural soils and their implications for improving P management. We gathered data on P input from feed and fertilisers and output in harvested products from farmer's surveys, unpublished reports and the literature to calculate PBE. We obtained for crop and pasture regions of south-west of WA (1) 109 000 soil test data for 2008-2010 from CSBP and (2) 8000 published temporally referenced soil test data. PBE ranged from 11% during sheep production to 48% during cropping. Phosphorus applied in excess of product removal ranged from 9.1 kg P ha^{-1} yr^{-1} in sheep to 6.1 in cropping. This built up available P and the amount and pattern of accumulation depended on the P buffering index of the soil, the length of time since land clearing and the rate of P input. Sixty three to 89% of soil samples under pastures and crop reached or exceeded critical values (CV) for near-maximum production. Agronomic efficiency (yield increases with P additions compared with no-P control) is close to zero in these soils and this should be offset by high PBE. A transition from P build-up to P maintenance practice using less P (the maintenance rate) has not occurred in WA. The result is low agronomic efficiency that is not offset by high PBE. The problem is compounded by over 50% of the 109 000 soil samples having soil acidity and other nutrient constraints to yield. Alleviating these constraints will improve yields and PBE. For soils that exceed their CV, there is a need to develop P maintenance practices to improve the financial and environmental outcomes of P use.

Do soils recover after being altered in bushfires?

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Bushfires are very common in Australia as many Australian native plants are highly combustible. Soil heated in a bushfire was collected at Wundowie in the Darling Range, Western Australia. The samples were taken from from under and adjacent to burnt Eucalyptus and grass tree (Xanthorrhoea pressii) logs. Conventional and synchrotron XRD patterns of heated and unheated soil show the effect of fire on soil minerals. The main crystalline compounds of unheated soil are quartz, kaolinite, gibbsite and goethite. In heated soil, kaolinite had dehydroxylated into metakaolinite, gibbsite altered into an amorphous phase, while goethite transformed into hematite (hydrohematite). The bushfire added calcite in plant ash to the soil and considerably increased the pH and EC of the soil. The increases in EC simply reflect the addition to the soil of soluble salts in plant ash. Heating increased amounts of extractable Al, Fe and Si due to crystalline minerals becoming amorphous as they were dehydroxylated by heating. Dehydroxylation of pure minerals (kaolinite, goethite and gibbsite) was also investigated in the laboratory and rehydroxylation under humid conditions was evaluated. Kaolinite, goethite and gibbsite dehydroxylated to form metakaolinite, hematite and boehmite respectively. Rehydroxylation of dehydroxylated gibbsite was extensive during hydrothermal treatment at 95^{o}C and after 14 days had formed boehmite, bayerite and gibbsite. The process was much slower at 55^{o}C. XRD patterns of metakaolinite and hematite subjected to rehydroxylation did not change but these materials acquired structural water. Specific surface area for all three heated minerals increased substantially during wet incubation. Clearly dehydroxylated minerals and possibly their rehydroxylated forms are present in naturally heated soils and may exert significant effects on the chemical behavior of the soil.

Pollutant removal in a stormwater biofilter is influenced by plant species, the presence of a submerged zone with carbon addition

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In stormwater biofilters, the type of plant species and the presence of a submerged zone (SZ) with carbon (C) addition may influence pollutant removal under wet-dry climatic patterns. A glasshouse experiment using two plant species (*Baumea juncea* and *Melaleuca lateritia*) with or without SZ and C addition, as well as *Baumea rubiginosa* and *Juncus subsecundus* with SZ and C addition was conducted to investigate the removal of total suspended solid (TSS), nutrients (NH_4-N, NO_x-N, total dissolved N/TDN, total N/TN, filterable reactive P/FRP, total dissolved P/TDP and total P/TP) and metals (Cd, Cu, Pb and Zn) from simulated stormwater in biofilter columns during 20 months of plant growth. All plants grew vigorously and developed well in the biofilters, but plant growth was better in the treatments with SZ than without. The removal of TSS, nutrients (except for NH_4-N and FRP) and metals (except for Cd and Zn) were significantly enhanced in the planted treatments with SZ. The removal of N was significantly higher in the planted treatments with SZ than in the no-plant treatment with SZ, whereas the removal of TSS, P (except for FRP) and metals was not significantly different between the plant presence and absence. Although the different plant species contributed differently to nutrient and metal removal, it was not possible to discriminate the performance in terms of plant growth and pollutant removal either among the four species in treatments with SZ or between the two plant species in treatments without SZ. The benefits of a SZ with C addition for nutrient removal in the planted biofilters could be due to increased denitrification and improved plant growth. The influence of a SZ on metal removal could be linked to changes of pH and redox in media, resulting in different adsorption and retention of metals in the biofilters. It is recommended that the selected native species combined with a submerged zone with C addition should be adopted in constructed biofilters in Western Australia.