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Hydrology, carbon and contours - the future of farming

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Abstract

Since settlement Australian agriculture has transitioned from hydrated carbon rich landscapes abundant in trees and diverse pastoral systems to a continent dominated by low carbon soils, overgrazed grasslands and vast fields of annual monoculture crops. Inappropriate farming practices including deforestation have led to longer intervals between sporadic and extreme rain events, highly incised streams and declining aquifer recharging. Landscape drainage has had a sizeable hydrological impact resulting in significant drops in annual rainfall and increased desertification. All this culminated in the uncontrolled wildfires that took place in 2019 and 2020 and extreme floods in 2021 and 2022.

Research indicates that these water-retention measures and practices can lower the regional temperature by 1.6°C and have the potential to increase production by 15-45% adding

significantly to national food security. Further, they provide tangible ways to reduce the intensity of Australia's, Europe's, Asia's and North America's droughts, fires and floods.

Keywords: Desertification, contour farming, food security, migration

Changes in the Australian landscape since European settlement

Research indicates that Australia is currently experiencing a significant collapse in nineteen ecosystems that have an impact on biodiversity, human health, and well being (Bergstrom et al., 2021). So critical is the issue that agronomically, this collapse is severely affecting soil health, plant diversity, water availability, soil erosion and production issues exacerbated by extremes in weather.

Due to the uniqueness of the landscape, many of Australia's first explorers found that the waterways were completely different to those in Europe. Dr Johann Lhotsky, in an expedition from Sydney to the Australian Alps in 1834, described Australia's waterways as a highly characteristic chain of ponds with round or oval basins 6-66m in diameter, fed by subterraneous springs (Lhotsky, 1835). The explorer Charles Sturt, when travelling through the Macquarie Marshes of New South Wales (NSW), describes the landscape as a flat country of successive terraces and an unbroken expanse with huge belts of reeds that extend as far as the eye could reach (Sturt, 1834). The Surveyor General and explorer Thomas Mitchell described the Darling River as a "chain of ponds" and the Murray River as "rising ground of a river-berg" (Mitchell, 1839). The definition of berg in South Africa means hill and river-berg describes a river that wasn't incised but rather slightly raised above the surrounding floodplains. After a rain event, these perched shallow water holes would spill out of the wetlands and spread across the floodplains on either side (Norris & Andrews, 2010). In the Southern Tablelands of NSW, many drainage lines contained chains of ponds which were later destroyed from 1840-1850 by the ringbarking of trees, introduced livestock and rabbits (Eyles, 1977). Over the last 200 years these unique wetlands have been drained by the settlers, resulting in Australia currently having only 3% of its landmass as wetlands (Junk et al., 2013).

Since European settlement in 1788 the environment has dramatically changed impacting on soil carbon, soil erosion and water quality. Research indicates that soil organic carbon (OC) levels between 1860-1990 have dropped more than 39% in many regions of Australia (Grace et al., 2019). In 1843, the Polish explorer, Sir Paul Edmund Strzelecki, collected soil samples from a number of regions in Australia. Analysis of the best soils at the time showed a range of 2.2-37.5% organic matter with the worst soils showing 2.2-10.6% organic matter (De Strzelecki, 1845). Many soils have lost more than 3% OC, equating to a potential water holding capacity shortfall of at least 504,000 L/ha (Jones, 2010), (Morris, 2004). This is water that holds valuable nutrients and organic compounds that would normally refill at every rain event.

Australia’s biodiversity is unique with its collection of 600-700,000 species, having 21,000 plant species and 10% of the world’s biota (Broadhurst & Coates, 2017). Developing settlements in Australia between 1788-1840 negatively impacted this biodiversity through land clearing and damage from sheep and cattle that led to extensive erosion, the introduction of rabbits, foxes, cats and a decline in animal and plant life (Cook, 2021). This has continued into the 21st century with the current loss of habitat seen as a major reason behind the biodiversity collapse, and species extinction believed to be the result of an additional 7. 7 million ha cleared in Australia between 2000-2017 (Ward et al., 2019).

Desertification not drought

The term desertification refers to a form of land degradation involving the expansion of aridity across the landscape and consequent reduction in biological, and thus, economic activity (Vogt et al., 2011). It leads to the depletion of sediment, soil organic matter and nutrients essential for revegetation following rainfall. Desertification is caused by climatic and human induced activities like deforestation, overgrazing and poor agricultural practices (Williams, 2015). According to the USDA’s Global Desertification Vulnerability Map, Australia contains vast areas of high to very high desertification vulnerability (Eswaran & Reich, 2003).

Australia is a unique continent with six climatic zones including equatorial, tropical, subtropical, desert, grassland and temperate (Meteorology, 2001). Australia’s central deserts and the surrounding grasslands make up more than 50% percent of the Australian mainland. When these grasslands begin the process of desertification, the whole region acts like an open oven door, furthering vegetation decline and drying the forests, making them prone to extreme bushfire events. This situation is currently critical to the extent that researchers claim that recent droughts, including the Millennium Drought (2001-2009), are without precedent and may be the worst seen in 400 years (Freund et al., 2017).

One of the primary drivers of drought and desertification in Australia is deforestation. Since 1788, Australia has lost nearly 40% of its original forests with the remainder highly fragmented, with closed forests accounting for only four percent of its land mass, one of the lowest in the world (Bradshaw, 2012). During the period 2010-2018, Land Use Change and Forestry (LULUCF) data indicates that sixty five percent of Australia's land clearing occurred in Queensland (QLD) (Marinova & Bogueva, 2022). Incidentally, this corresponds with the long drought periods experienced recently in the state of QLD (Steffen et al., 2018).

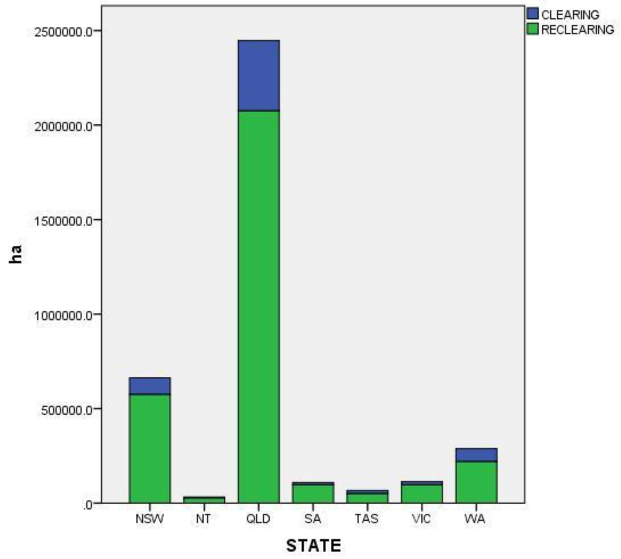

Figure 1 Land Clearing in Australia (2010-2018) (Marinova & Bogueva, 2022)

The other major contributor to desertification in the Australian landscape is overgrazing by introduced livestock and feral pests. Since settlement, overgrazing by livestock has played a significant role in soil compaction, increased surface water flow and gully erosion (McCloskey et al., 2016). This has led to an incised landscape, where gullies become deeper contributing to the draining and drying of the landscape. The original grasslands full of perennial grasses, legumes, forbs (herbaceous flowering plants) and scattered trees were replaced with simplified introduced grass pastures and annual grain cropping. In some areas, these introduced grass species *Cenchrus ciliaris* (buffel grass) quickly became invasive (Marshall et al., 2011). There appears to be a recurring pattern of longer and more severe droughts, a sure sign that desertification is now the norm in many parts of Australia. So severe is the problem of overgrazing leading to desertification that after years of extreme dry conditions vast regions of Western QLD in 2021 no longer responded to significant rainfall events (Barker, 2021). Another negative aspect of desertification and extensive droughts is that they increase the soil's ability to repel water adding to the severity of flooding that commonly follows long dry periods (Mao et al., 2018).

Desertification results in a collapse of ecosystem services (ES) that directly affects the productivity in each region. Globally ES losses in 2011 caused by inappropriate land use are estimated to cost between four and twenty trillion dollars per year (Farber & Turner, 2014).

The small water cycle and the biotic pump

The latent heat of vaporisation (heat of evaporation) is the amount of heat required to transform water from a liquid to a gas (Schneider et al., 2010). Evaporating water takes this energy from the surrounding area cooling it in the process. Across a surface this process is called evaporation, across a plant it is called transpiration. The combination of both these processes across a landscape is called evapotranspiration and together with condensation forms the basis of the small water cycle. The formation of clouds occur when this hot air rises and the water vapour within condenses on small particles called cloud condensation nuclei (CCN) (Williamson et al., 2019). Some of these CCN include dust, clay particles, chemicals and organic aerosols like carbon, pollen, bacteria and fungi. When the water condenses forming rain the energy is released as latent heat causing the air to rise further.

Sensible heat on the other hand is the energy required to change the temperature of a substance without changing its phase and this has played a significant role on the hydrological cycle (Myhre et al., 2018). Sensible heat comes from solar energy heating the soil or air itself. In a landscape full of water bodies, the majority of the solar energy is used for evaporation and the remainder, for sensible heat, heating the ground, and reflection or photosynthesis. In drained landscapes (like Australia, North America and large expanses of Europe), most of the incoming solar radiation is converted to sensible heat, while in the damp areas or vegetated areas it converts to evaporation or photosynthesis (Kravčík et al., 2007). Water surfaces, damp areas and plants protect the ground from overheating, increase infiltration, reduce water runoff and provide flood mitigation.

The small water cycle refers to the water that evaporates from the land that then precipitates nearby. It can be upward of 50% of the rainfall in a given catchment or region, though this depends on bodies of water, green vegetation, soil organic matter and trees (Sheil & Murdiyarso, 2009). In just over 200 years since settlement, Australian land managers have deforested and drained the landscape and as a result, destroyed the rich diversity of grasslands and significantly reduced the small water cycle. Through the adoption of long fallow periods on bare soil over summer and autumn, there has been a reduction in landscape transpiration, a decrease in the release of bacterial and other aerosols from forests, and consequently a significant reduction of inland rain, fog, and mist. The historical transition from perched waterways and rivers with floodplains or slightly incised landscapes to highly incised gullies has led to the severe drying of the landscape and increased sensible heat, further driving away cloud formations. In south west Western Australia (WA), land clearing and cropping has led to significantly less rainfall between 1958-2007 forcing the grain growing region to move even further south west (Nicholls, 2010).

This draining and drying of the landscape is a global problem that is accelerating. Recent research, using tree-ring stable carbon and oxygen, indicates that since 2015, European summer droughts are occurring with a frequency that is unprecedented in the last 2110 years (Büntgen et al., 2021).

Moving from a carbon-centric climate model to one that highlights the complex interactive cooling effects of water, trees and forests, must be a priority in all agricultural, land management and financial decisions (Ellison et al., 2017). This will be critical for reducing sensible heat and increasing infiltration to the underground aquifers. Underpinning this is the need for managers and property owners to build a soil sponge of diverse carbon fractions, bio-diverse plant and soil organisms including mycorrhizal fungi, to further cool the landscape (Jehne, 2019).

The biotic pump theory states that forests not only contribute to rainfall but are also significant in the creation of winds that distribute the rainfall. Russian physicists Anastassia Makarieva and Victor Gorshkov discovered that the boreal forests of Russia draw in moisture from the ocean that ends up in China and Mongolia (Makarieva & Gorshkov, 2007). Research indicates that this also occurs in the Amazon where large scale flows in atmospheric water vapour over forests through evapotranspiration creates a low pressure system that brings in rain from the Atlantic (Makarieva et al., 2014). Moreover, forests are critical in the control of precipitation, streamflow, groundwater storage and moisture circulation over vast distances (Costa-Cabral, 2015).

Contour farming examples around the world

In order to regulate microclimates using evapotranspiration, water needs to be held within the landscape as wetlands and forests (Hesslerová et al., 2019). Contour farming is an ancient agricultural practice that mimics wetlands by building level banks in order to hold and conserve water, reduce soil erosion, and minimise nutrient loss and fertiliser costs (Van Vlack & Clapp, 1940). Variations of the practice that have been utilised internationally include terrace farming in Asia and Europe, bund farming in Africa, Syntropic farming in South America and contour cropping in the US.

Terrace farming has been a cornerstone of agricultural civilisations for thousands of years. It originated in China with the earliest evidence of domesticated rice production dating from 3,500 years ago in the interior of Sulawesi Island, Indonesia (Deng et al., 2020). It is also found in the Lao Cai Province in the mountainous region of northern Vietnam, historically introduced by China to help farmers transition away from 'slash and burn' to permanent farming on steep slopes (Sakurai et al., 2004). With the help from stone masons, terrace farming was used by the Inca's (1438-1533) in Peru to stabilise food production close to settlements at altitudes where limitations due to low temperature and cloud cover abounded (Niles, 1982). In the Philippine Cordilleras, a UNESCO World Heritage Site, rice terraces have also been continually farmed for more than 1000 years (Kikuchi et al., 2014). In the famous Piedmont region of northern Italy, terrace farming has been used since at least the 18th century (Cevasco, 2013) with estimations of the area farmed as exceeding 170,000 ha (Varotto et al., 2019). During the 11th century terraced vineyards were developed in the Lavaux region in Switzerland, another UNESCO World Heritage site (Reynard & Estoppey, 2021). Terraced orchards used in southern France and throughout the Roman times have been dated back to the Phoenicians 2500 years ago (Lowdermilk, 1948).

In South Africa, stone contour bunds have historically been used since the Bokoni civilisation over 500 years ago (Delius et al., 2012). Together with livestock management, these terraces assisted the farmers in the production of millet, maize, beans and sorghum. Variations of water conservation techniques in Africa include stone bunds, soil bunds, hedgerows or grass strips, trash lines for scraps along the contour and bench terraced areas leading to yield increases of up to 80% in extreme climatic conditions (Wolka et al., 2018). In semi arid areas of Zimbabwe, standard contour ridges have been superseded by three in-field water harvesting technologies like fanya juus terraces, infiltration pits and contour ridges with cross ties

(Nyagumbo et al., 2019). Such areas are often planted with *Pennisetum purpureum (*napier grass) for livestock, bananas and grevillea trees for agroforestry.

Contour strip cropping in the United States began in the 1930's following promotion by the U.S. Soil Conservation Service to reduce soil erosion during and after the Dust Bowl (Kell, 1938). Prior to this programme, which was later adopted in Australia by the NSW Soil Conservation Service (SCS), parallel and strip cropping were frequently used, resulting in excessive erosion across the country. Farmers in the US are now paid to rest their paddocks and implement practices to reduce erosion or protect natural resources and wildlife (Lichtenberg, 2019). These programmes are critically important for addressing non-point source pollution from agriculture. In India the introduction of soil and water conservation using contour banks by Dr. Rajendra Singh has led to hundreds of catchments being rehabilitated (Das, 2015).

Syntropic farming (or successional agroforestry) is the brainchild of Ernst Götsch who after moving to Bahia in Brazil discovered a way of combining farming and agroforestry. He would rehabilitate clear felled land by planting multi species on a contour, harvesting and returning the plant biomass to the soil and maximizing evapotranspiration (Götsch, 1995). Syntropic farming lowers soil temperature, increases infiltration and raises soil moisture when compared to conventional monoculture farming in tropical conditions (Damant, 2018). It has been adopted in many countries now, combining scientific and traditional knowledge using stratification or layered photosynthesis to promote ecological succession and regenerate native ecosystems (Andrade et al., 2020).

When adopting these international practices in Australia, a number of issues that need to be considered. The alteration of any watercourse is limited to Order 1 and Order 2 streams as defined by the Strahler stream ordering method (Environment, 2023) as observed on any topographic map. According to the SCS, once the type of contour bank is selected, the maximum length of a contour is dependent on the slope of the land. At 1% slope the maximum length of a grassed contour is 2500m whereas at 10% slope the maximum length is 300m (Shilton et al., 2015). Further, spillways width is dependent on spillway discharge (m3/s) and slope of the land (SA, 2011). Farm design for cooling benefit can be further enhanced by planting deciduous fodder trees, fruit trees, nut trees and shrubs below the contour and avoiding the fire loving Myrtaceae family (with higher oil content). At each rain event the trees are watered automatically. With incised gullies along Order 3 and above streams, ephemeral frog ponds using living clumping bamboo and criss-crossed bamboo poles provides an ideal way to stop soil erosion, revegetate the landscape, provide habitats for water invertebrates and reduce sensible heat transfer (Tardio et al., 2018).

Three unique Australian hydration techniques - Keyline, Permaculture and Natural Sequence Farming.

Australia has developed some unique internationally recognised agricultural production systems focusing on water management (Massy, 2013), (Massy, 2020), (Smith & Dawborn, 2011). These are Keyline Farming (Yeomans, 1958), Permaculture (Mollison & Holmgren, 1978), (Mollison, 1979), and Natural Sequence Farming (Andrews, 2006). In all three systems, the focus is on creating a productive microclimate for plant and animal production. Yeomans was the first to introduce farm design principles to hydrate the farm which were later adopted and modified in Permaculture designs and zoning practices (Mollison, 1988). By contrast, Andrews envisioned the landscape as it looked prior to European settlement, how these processes functioned through natural wetlands; and how some could be reinstated using simple techniques (Andrews, 2008). During this period, the conventional approach, led by the NSW Soil Conservation Service using USDA soil conservation experience, was educating farmers on how to safely drain water from the landscape using earthen, rock and concrete structures (NSW, 2023).

The development of Yeomans' Keyline farming was influenced by the English agricultural scientist, Sir Albert Howard (Howard, 1943) and the founder of the UK Soil Association, Lady Eva Balfour (Balfour, 1943). Both focussed on the importance of building topsoil and soil humus. Yeomans, building on NSW Soil Conservation Service techniques, observed that water could be stored and moved from a particular bank at the change of slope called the Keyline (Yeomans & Yeomans, 1993). This Keyline determined the layout of farm dams, gravity irrigation, cultivation, fences, roads and tree belts. Farm dams had valves that could empty the water into a bank below so that the water could be moved by gravity anywhere on the property. This served in times of bushfire when livestock needed to be protected. Yeomans also introduced the Graham Hoehme Chisel Plow, Keyline Pattern plowing techniques that move water from the gully to the ridge, and the narrow tyne subsoiler that penetrates and develops deep soils (Yeomans, 2005). However, the later should never be used on dispersive sodic soils where tunnel erosion can quickly develop. The Keyline system has now been adopted internationally for many different farming enterprises, soil types and ecosystems (Doherty, 2015).

Permaculture ideas began to spread in the 1980s when conventional farming was being challenged for its unsustainability (Beus & Dunlap, 1990). It is founded on 'permanent culture' as agriculturally productive ecosystems integrate with the landscape to provide food, shelter and energy with minimal impact (Ferguson & Lovell, 2014). Permaculture adopted the parts of Yeomans' final book *The City Forest* which introduced sustainable urban development (Yeomans, 1971). Permaculture expanded on this design concept to include management zones beginning at the principle household expanding out to the property boundary.

Central to Permaculture is the management of water and adoption of Keyline's banks to move water from one area to another. In Permaculture the term swale is used to describe an earthen embankment which either holds water where it is, lateral water movement only, or transports water on a slope to a storage area (Revitt et al., 2017). Permaculture has become a widely practised agroecology (Hathaway, 2016), (Krebs & Bach, 2018) and is acknowledged by the United Nations Convention to Combat Desertification (UNCCD) for its capacity to prevent land degradation (Cowie et al., 2018), (Fiebrig et al., 2020).

Natural Sequence Farming (NSF) is a landscape regeneration and hydration practice founded by Peter Andrews in the 1970's. It provides practical solutions to landscape cooling, renovations of eroded landscapes, salinity management and rehydration (Hurditch, 2015). Natural Sequence Farming design is unique in reproducing hydrostatic pressure that existed prior to European settlement. Ephemeral perched water bodies (wetlands) are created by carefully constructing contour banks and permeable ponds to rehabilitate degraded landscapes (Williams, 2010).

These NSF contour banks, unlike Keyline banks and Permaculture swales, are constructed on the true contour from only A horizon soil material to ensure a film of fresh water is always covering any salty subsoil reducing potential salinity issues. Contours are located towards the highest part of the catchment with multiple spillways located to give the structure unlimited capacity. Both Permaculture and NSF promote the use of willows because they live in recharge areas reducing soil erosion, holding back ponded water and retaining nutrients (Wilson, 2006). The recycling of nutrients is encouraged in NSF design by activities that move them from the lower filtration to higher accumulation areas. This includes carting hay and compost to the highest part of the property while planting windbreaks and fodder trees below the highest contour bank.

Permeable ponds are also used in NSF in eroded gullies to reduce soil and organic nutrient loss from the farm. The building of many thousands of similar permeable rock structures over 30 years in the Turkey Pen Watershed of the Chiricahua Mountains in South East Arizona, led to a 50% reduction in flash floodings and an increase in overall water availability by 28% (Norman et al., 2016), (Norman, 2022).

Weeds as indicators of plant succession, soil health and biodiversity

Primary succession occurs when plants grow in areas devoid of soil that is apparent following larva flow, sand dunes or glacial retreating (Nara et al., 2003). Secondary succession occurs when plants grow following a major disruption as in the case of fire, drought, clearing or soil disturbance (Mahaut et al., 2020). In primary plant succession initial plants are often described as pioneer plants, but in secondary succession they are referred to as weeds (Numata & Holzner, 1982). Weeds are unwanted plants in a particular place at a certain time and have historically included herbs, grasses, legumes, fibre and medicinal plants (Harlan & deWet, 1965).

The management of weeds is becoming increasingly important due to climate variability and the ability of such plants to adapt and readily migrate (Ramesh et al., 2017). In Australia many C4 plants and weeds are expanding their geographic range southwards and in the next century, weed management will need to research new methods of how to manage this advancing front (Scott et al., 2014). The fast pace at which weeds are adapting makes it urgent to transition away from herbicides towards natural weed prevention (MacLaren et al., 2020). With increasing herbicide resistance in weeds, there is much interest in long term solutions involving an integrated and ecological approach to weed control (Scavo & Mauromicale, 2020), (Bagavathiannan & Davis, 2018). A practical example is the summer legume *Lablab purpureus* (lablab bean) and its allelopathic effect on suppressing weeds in the next autumn wheat crop (Singh et al., 2005). Allelopathy plays an essential role in weed succession and agroecosystems design (Chou, 1999).

Historically, cultural management of weeds has included adaptive management practices like rotations (King, 1951), (Cocannouer, 1950), (Pfeiffer, 1975), (Walters, 1991), (McCaman, 1994), (Millar, 1995), (Collins, 2017). A common theme in many of these books, backed anecdotally by farmers and gardeners is the concept that weeds are bio-indicators of soil fertility (Hill & Ramsay, 1977). Integrated Weed Management strategy aims not to eradicate weeds but to regulate populations to limit negative impacts (MacLaren et al., 2020). The diversity of weeds has also been found to modify the microbiome of the soil, benefiting microorganisms that support their growth and development (Trognitz et al., 2016).

In this new era of regenerative agriculture, there is a need to implement improved agronomic research founded on restoring soil health and reversal of biodiversity loss (Giller et al., 2021). One of the hallmarks of this research is increasing soil carbon sequestration, retaining soil moisture and encouraging biodiversity (Gosnell et al., 2019). The integration of ecology into weed science and agronomy is critical (Booth & Swanton, 2002), (Booth et al., 2003). Weed diversity and weed succession are also essential in agricultural systems as food sources for bees, insect pollinators and birds (Gaba et al., 2016). Research indicates that increased plant diversity also increases soil microbial activity and soil carbon (Lange et al., 2015).

Practices that build carbon, biodiversity and water holding capacity of the soil

Soil biota provides a critical role in the long term management of soil carbon and the stability of agricultural ecosystems (Barrios, 2007). There are many agronomic practices used by organic regenerative farmers to maintain and improve ecosystem services which lead to better soil structure, increased water infiltration, moisture storage and nutrient recycling (Pereira et al., 2018). Building soil carbon relies on a microbial pathway by which carbon exudates move from the plant root to the rhizosphere (Sokol & Bradford, 2019). Mycorrhizal fungi assist this pathway by significantly expanding the effective root area and assisting water uptake during dry periods (Allen, 2007). The most common of these practices include green manure (cover) crops, compost, windbreaks, long term rotations and livestock management. Some of these practices, especially cover crops and compost, have led to significant increases in soil organic carbon levels (Crystal-Ornelas et al., 2021).

Green manure (cover) crops utilise diverse plant species to allow farmers to reduce fertiliser costs, eliminate herbicides, improve soil health, prevent soil erosion, conserve soil moisture, protect water quality and provide habitat for beneficial insects and predators (Clark, 2008). Since 1991 in Bismarck, North Dakota, one farm has increased soil organic matter from 1.9-6.1% and increased soil infiltration rate from 0.5-8 inch per hour using cover crops, rotations and integrated livestock grazing (Chico, 2022). Studies also indicate that although monoculture cover crops may produce more biomass, multi-species crops yield more ecosystem services (Finney et al., 2016). One of the reasons for this may lie in the phenomena of quorum sensing, a process that involves the activation of a particular concentration of rhizo-bacteria compounds that benefit a plant's nutrient uptake and disease control (Babalola, 2010). An example of this is recorded in a series of field trials where 10 cover crop species where planted separately, and all died due to adverse climatic conditions; whereas the trial plot with all 10 species together thrived (Brown, 2017). The termination of cover crops can be achieved without soil disturbance or chemicals by using crumple rollers that crush the stem of the crop just prior to flowering (Seidel et al., 2017).

A review of long term experiments in use of organic amendments indicates decreased soil bulk density and increased soil organic carbon, aggregate stability and crop yields (Diacono & Montemurro, 2011). Compost and biochar have also shown potential in amending saline and sodic soil (Chaganti et al., 2015). Compost also provides a wide selection of nutrients and organic compounds (QUT, 2022) with some composts producing more biomass and soil carbon due to the development of soil microbial communities (Johnson et al., 2015).

International studies indicate that reducing the wind across paddocks reduces stomatal water loss and can lead to crop and pasture production increases between 15-45% (Geno & Geno, 2001). In Europe, alley cropping agroforestry has been shown to provide benefits through abiotic factors (nutrient cycling and improved microclimate) and biotic factors (biodiversity) (Quinkenstein et al., 2009). In Australia the integration of agroforestry in farming operations has been slow due to a lack of data on productive benefits to both plants and livestock (Baker et al., 2018). By 2100, continued amalgamation of properties and land clearing for cropping efficiency is expected to lead to further reductions of trees up to 30% and a loss of birdlife and bats by 50% (Fischer et al., 2010). Agroforestry will be a critical component in reducing wind flow, sediment loss, flood damage and increasing biodiversity.

Crop rotations play an essential role in controlling diseases, reducing the costs of fertilisers, improving soil health, improving yield stability and increasing long-term profitability (Selim, 2019). Research indicates that progression from a two year soy/corn rotations to more complex 3 and 4 year rotation with legumes and cow manure can maintain yields (Davis et al., 2012). Further evidence from 11 experiments over 347 sites shows that rotation diversity reduced the risk of crop failure during drought conditions through improvements in soil health, soil biota and organic matter (Bowles et al., 2020). Other studies point to the importance of grasslands as part of the rotation, increasing the connectivity of pore spaces, increasing hydraulic conductivity and reducing greenhouse gas emissions (Neal et al., 2020). The use of hemp for seed or fibre in a farming rotation is also valuable as it produces up to 10t/ha dry matter eliminating weeds and giving thermal protection to the soil (Cole & Zurbo, 2008).

Livestock grazing as part of an integrated farming practice is important in building soil carbon. Due to the activity of bacteria and fungi, there is evidence to suggest that soil organic matter stores more carbon in the top 2m soil horizon than plants biomass and the atmosphere combined (Jackson et al., 2017). In pasture management both the diversity of plant species and grazing of no more than 50% of the available green leaf matter at one time is critical to increase soil organic matter levels (Jones, 2018). In an eleven year study, grasslands without legumes increased soil carbon and nitrogen levels by 18% and 16% where there were more than 8 species in the mixture (Cong et al., 2014). In another nine year experiment evaluating forage production, a five species mixture of grasses, legumes and a non-legume herbaceous plants produced 31% more biomass and 300% more carbon (Skinner & Dell, 2016). In a fifteen year grassland experiment, diverse pastures of up to 60 species showed a number of beneficial effects on ecosystem functions including pollination, increased parasitism of pests, weed suppression, pathogen resistance, increasing soil carbon and water holding ability (Weisser et al., 2017).

Studies indicate that well managed grazing operations using multiple paddocks and short grazing periods achieve both productive outcomes and increases soil carbon, plant diversity, soil biota, water retention and nutrient recycling (Teague & Barnes, 2017). Regenerative Ranching or Wholistic Grazing Management can both educate farmers about ecosystem functions whilst providing solutions to carbon sequestration (Gosnell et al., 2019). Appropriate regenerative crop and grazing management protects essential ecosystem services by increasing soil carbon sequestration and reducing soil erosion (Teague et al., 2016). Recently it has been shown that improved grazing management can increase soil carbon by 20.6% and reduce soil respiration of greenhouse gases by 19.5% (Johnson et al., 2022).

Opportunities to increase hydration through systems research

A study of Canadian net farm income since 1980, shows the cost of production has risen considerably forcing many farms to pursue off-farm income (Qualman, 2017). The study highlights the rise of agribusiness supplier costs and other economic challenges experienced by many farmers. Australia faces similar challenges, with diminishing farm returns reinforcing the need to investigate organic regenerative agronomic practices. These alternatives have the capacity to provide ecosystem services that build soil health, increase biodiversity, hydrate the landscape while at the same time reducing the costs of production. An example of this can be found in the multiple benefits of applying compost to soil that not only provides a broad spectrum of nutrients but also increases soil carbon at depth by up to 12.6% thus increasing the water holding capacity of the soil (Tautges et al., 2019).

In developed countries, universities and research institutions have focused on the benefits of technology transfer (Sime, 2018). However, this research does not take into account the collateral costs of environmental externalities stemming from mechanised production and petro-chemical fertilisers - declining soil, water, air, and habitat quality (Weersink & Pannell, 2017). With declining net farm returns and increasing farm debt, there is a growing interest in organic regenerative farming systems that are socially responsible, economically viable and ecologically reparative (Ikerd, 2021).

Systems research focuses on the biosphere as an interconnected network. It moves away from anthropocentric towards ecocentric attitudes (Thompson & Barton, 1994). Systems research in agriculture has its foundation based in ecology and how living things interact with the physical world. This is seen in organic regenerative grazing where a “community of practice” has developed with farming innovators using the logic of ecosystems to solve complex problems (Cross & Ampt, 2017). This ecological approach is slowly being extended to the investigation of agricultural practices that influence soils, plants, and ultimately the human micro biome (Busby et al., 2017), (Altieri & Nicholls, 2020).

There is an urgent need in the 21st century, to focus research on organic regenerative semi-closed systems and particularly on hydration of farming landscapes (Pearson, 2007). Research in eastern Germany, Czech Republic, and Slovakia using landscape-based water retention measures as nature based solutions to climate change indicates temperatures will cool by 1.6°C and arable land will increase crop production by € 80 ha^{-1} (Sušnik et al., 2022). Slowing down the movement of runoff provides additional water to humans, the environment and atmosphere and is a fundamental climate change mitigation tool (Kravčík et al., 2020).

In Australia, this research should be part of a national integrated hydrology management plan that could be driven in part, by the farming community and private public partnerships. To achieve these objectives, there also needs to be a progressive change in the mindset of those who own and manage the land (Sanford, 2011). For Australia to achieve food security, as well as be a major food exporter by 2050, farming research and policies should focus on agricultural practices that reinstate the hydrology of each catchment, control excessive water runoff, and recharge groundwater (Wichelns, 2015). This can be done by implementing system based conservation and eco-intensive agriculture, controlling water, eliminating carbon and nutrient loss through soil erosion, improving water infiltration and implementing the law of return (Lal, 2020a), (Lal, 2020b). As global weather patterns become more unreliable and extreme, the importance of building ecosystem services that retain soil and water in each catchment will determine how resilient we become.

Discussion

Since European settlement of Australia, there has been an accelerated dehydration of the catchments brought on by overgrazing, land clearing, the introduction of rabbits and drainage of the wetlands. These actions led to incised landscapes with severe soil erosion and expanding desertification. This altered the hydrology of the continent resulting in less small water cycles and biotic pump activity.

As a matter of urgency, countries around the world need to address their susceptibility to extreme weather events by re-engaging the hydrology of each catchment. From a food security perspective reversing desertification helps reclaim unproductive lands and reduces migrations to larger cities or other countries. Practical steps towards achieving such agronomic improvements have been used over a long period in human history and can be initiated again at any scale. Agriculture has the potential to rapidly lower the temperature of the landscape by 1.6°C while providing considerable economic benefits at the same time.

References

[1] Allen, M. F. (2007). Mycorrhizal fungi: highways for water and nutrients in arid soils. Vadose Zone Journal, 6(2), 291-297. https://doi.org/(https://doi.org/10.2136/vzj2006.0068).

[2] Altieri, M. A., & Nicholls, C. I. (2020). Agroecology and the reconstruction of a post-COVID-19 agriculture. The Journal of Peasant Studies, 47(5), 881-898. https://doi.org/(https://doi.org/10.1080/03066150.2020.1782891).

[3] Andrade, D., Pasini, F., & Scarano, F. R. (2020). Syntropy and innovation in agriculture. Current Opinion in Environmental Sustainability, 45, 20-24. https://doi.org/https://doi.org/10.1016/j.cosust.2020.08.003

[4] Andrews, P. (2006). Back from the brink: how Australia's landscape can be saved. HarperCollins Australia.

[5] Andrews, P. (2008). Beyond the Brink: A Radical Vision for Australia's Landscape, ABC Books, Sydney.

[6] Babalola, O. O. (2010). Beneficial bacteria of agricultural importance. Biotechnology letters, 32(11), 1559-1570. https://doi.org/(https://doi.org/10.1007/s10529-010-0347-0)

[7] Bagavathiannan, M. V., & Davis, A. S. (2018). An ecological perspective on managing weeds during the great selection for herbicide resistance. Pest management science, 74(10), 2277-2286. https://doi.org/https://doi.org/10.1002/ps.4920

[8] Baker, T., Moroni, M., Mendham, D., Smith, R., & Hunt, M. (2018). Impacts of windbreak shelter on crop and livestock production. Crop and Pasture Science, 69(8), 785-796. https://doi.org/(https://doi.org/10.1071/CP17242).

[9] Balfour, E. B. (1943). The living soil. The living soil. (https://soilandhealth.org/copyrighted-book/the-living-soil/)

[10] Barker, E. (2021). Outback graziers left scratching their heads as rain fails to boost grass growth. (https://www.abc.net.au/news/rural/2021-03-08/rain-falls-but-fails-to-grow-grass-north-west-queensland/13216010)

[11] Barrios, E. (2007). Soil biota, ecosystem services and land productivity. Ecological economics, 64(2), 269-285. https://doi.org/https://doi.org/10.1016/j.ecolecon.2007.03.004

[12] Bergstrom, D. M., Wienecke, B. C., van den Hoff, J., Hughes, L., Lindenmayer, D. B., Ainsworth, T. D., Baker, C. M., Bland, L., Bowman, D. M., & Brooks, S. T. (2021). Combating ecosystem collapse from the tropics to the Antarctic. Global Change Biology, 27(9), 1692-1703. https://doi.org/ (https://doi.org/10.1111/gcb.15539)

[13] Beus, C. E., & Dunlap, R. E. (1990). Conventional versus alternative agriculture: The paradigmatic roots of the debate. Rural sociology, 55(4), 590-616. https://doi.org/https://doi.org/10.1111/j.1549-0831.1990.tb00699.xCitations: 194

[14] Booth, B. D., Murphy, S. D., & Swanton, C. J. (2003). Weed ecology in natural and agricultural systems. CABI. http://sherekashmir.informaticspublishing.com/437/1/9780851995281.pdf

[15] Booth, B. D., & Swanton, C. J. (2002). Assembly theory applied to weed communities. Weed Science, 50(1), 2-13. https://doi.org/https://doi.org/10.1614/0043-

1745(2002)050[0002:AIATAT]2.0.CO;2

[16] Bowles, T. M., Mooshammer, M., Socolar, Y., Calderón, F., Cavigelli, M. A., Culman, S. W., Deen, W., Drury, C. F., y Garcia, A. G., & Gaudin, A. C. (2020). Long-term evidence shows that crop-rotation diversification increases agricultural resilience to adverse growing conditions in North America. One Earth, 2(3), 284-293. https://doi.org/(https://doi.org/10.1016/j.oneear.2020.02.007).

[17] Bradshaw, C. J. A. (2012). Little left to lose: deforestation and forest degradation in Australia since European colonization. J Plant Ecol, 5(1), 109-120. https://doi.org/(https://doi.org/10.1093/jpe/rtr038)

[18] Broadhurst, L., & Coates, D. (2017). Plant conservation in Australia: current directions and future challenges. Plant diversity, 39(6), 348-356. https://doi.org/(https://doi.org/10.1016/j.pld.2017.09.005)

[19] Brown, G. (2017). Dirt to Soil: One Family’s Journey Into Regenerative Agriculture.

[20] Büntgen, U., Urban, O., Krusic, P. J., Rybníček, M., Kolář, T., Kyncl, T., Ač, A., Koňasová, E., Čáslavský, J., & Esper, J. (2021). Recent European drought extremes beyond Common Era background variability. Nature Geoscience, 14(4), 190-196. https://doi.org/https://doi.org/10.1038/s41561-021-00698-0

[21] Busby, P. E., Soman, C., Wagner, M. R., Friesen, M. L., Kremer, J., Bennett, A., Morsy, M., Eisen, J. A., Leach, J. E., & Dangl, J. L. (2017). Research priorities for harnessing plant microbiomes in sustainable agriculture. PLoS biology, 15(3), e2001793. https://doi.org/https://doi.org/10.1371/journal.pbio.2001793

[22] Cevasco, R. (2013). Piedmont. In Italian Historical Rural Landscapes (pp. 175-198). Springer. https://doi.org/(https://doi.org/10.1007/978-94-007-5354-9_7)

[23] Chaganti, V. N., Crohn, D. M., & Šimůnek, J. (2015). Leaching and reclamation of a biochar and compost amended saline–sodic soil with moderate SAR reclaimed water. Agricultural water management, 158, 255-265. https://doi.org/https://doi.org/10.1016/j.agwat.2015.05.016

[24] Chico, C. S. U. (2022). Gabe Brown, Brown’s Ranch, Bismarck, ND. https://www.csuchico.edu/regenerativeagriculture/demos/gabe-brown.shtml

[25] Chou, C.-H. (1999). Roles of allelopathy in plant biodiversity and sustainable agriculture. Critical reviews in plant sciences, 18(5), 609-636. https://doi.org/(https://doi.org/10.1080/07352689991309414)

[26] Clark, A. (2008). Managing cover crops profitably. Diane Publishing.

[27] Cocannouer, J. A. (1950). Weeds, guardians of the soil.

http://www.zetatalk11.com/docs/Plants/Weeds/Weeds_Guardians_Of_The_Soil_1980.pdf

[28] Cole, C., & Zurbo, B. (2008). Industrial hemp–a new crop for NSW. D. o. P. Industries, Ed, 801.

[29] Collins, P. (2017). The Wondrous World of Weeds. (New Holland Publishers)

[30] Cong, W. F., van Ruijven, J., Mommer, L., De Deyn, G. B., Berendse, F., & Hoffland, E. (2014). Plant species richness promotes soil carbon and nitrogen stocks in grasslands without legumes. Journal of ecology, 102(5), 1163-1170. https://doi.org/ https://doi.org/10.1111/1365-2745.12280

[31] Cook, D. E. (2021). Anthropogenic environmental change on the frontiers of European colonisation in Australia, AD 1788–1840. A reply to comments in Woodward (2020). Geomorphology, 373, 107234. https://doi.org/(https://doi.org/10.1016/j.geomorph.2020.107234)

[32] Costa-Cabral, M., & Marcelini, S. S. . (2015). The role of forests in the maintenance of stream flow regimes and ground water reserves: A review of scientific literature, Northwest Hydraulic Consultants (https://www.inputbrasil.org/wp-content/uploads/2015/05/The_role_of_forests_in_the_maintenance_of_stream_flow_regimes_and_ground_water_reserves_summary_Agroicone.pdf)

[33] Cowie, A. L., Orr, B. J., Sanchez, V. M. C., Chasek, P., Crossman, N. D., Erlewein, A., Louwagie, G., Maron, M., Metternicht, G. I., & Minelli, S. (2018). Land in balance: The scientific conceptual framework for Land Degradation Neutrality. Environmental science & policy, 79, 25-35. https://doi.org/https://doi.org/10.1016/j.envsci.2017.10.011

[34] Cross, R., & Ampt, P. (2017). Exploring agroecological sustainability: Unearthing innovators and documenting a community of practice in Southeast Australia. Society & Natural Resources, 30(5), 585-600. https://doi.org/https://doi.org/10.1080/08941920.2016.1230915

[35] Crystal-Ornelas, R., Thapa, R., & Tully, K. L. (2021). Soil organic carbon is affected by organic amendments, conservation tillage, and cover cropping in organic farming systems: A meta-analysis. Agriculture, Ecosystems & Environment, 312, 107356. https://doi.org/https://doi.org/10.1016/j.agee.2021.107356

[36] Damant, G. (2018). Can agroforestry improve soil water and temperature dynamics in agriculture? A case study with syntropic farming in Bahia, Brazil. European Agroforestry Conference-Agroforestry as Sustainable Land Use, 4th,

[37] Das, S. (2015). Dr. Rajendra Singh: His tryst with water and peace. Journal of the Geological Society of India, 85(5), 521.

https://link.springer.com/content/pdf/10.1007/s12594-015-0245-0.pdf

[38] Davis, A. S., Hill, J. D., Chase, C. A., Johanns, A. M., & Liebman, M. (2012). Increasing cropping system diversity balances productivity, profitability and environmental health. https://doi.org/(https://doi.org/10.1371/journal.pone.0047149).

[39] De Strzelecki, P. E. (1845). Physical Description of New South Wales and Van Diemen's Land: Accompanied by a Geological Map, Sections and Diagrams, and Figures of the Organic Remains. London: Longman, Brown, Green, and Longmans.

[40] Delius, P., Maggs, T., & Schoeman, M. (2012). Bokoni: Old structures, new paradigms? Rethinking pre-colonial society from the perspective of the stone-walled sites in Mpumalanga. Journal of Southern African Studies, 38(2), 399-414. https://doi.org/(https://doi.org/10.1080/03057070.2012.682841)

[41] Deng, Z., Hung, H.-c., Carson, M. T., Oktaviana, A. A., Hakim, B., & Simanjuntak, T. (2020). Validating earliest rice farming in the Indonesian Archipelago. Scientific reports, 10(1), 10984. https://doi.org/10.1038/s41598-020-67747-3

[42] Diacono, M., & Montemurro, F. (2011). Long-term effects of organic amendments on soil fertility. In Sustainable agriculture volume 2 (pp. 761-786). Springer. https://doi.org/(https://doi.org/10.1007/978-94-007-0394-0_34)

[43] Doherty, D. J. J., A. . (2015). Regrarian's eHandbook. Regrarians Ltd. (http://www.regrarians.org/regrarians-handbook/)

[44] Ellison, D., Morris, C. E., Locatelli, B., Sheil, D., Cohen, J. M., Murdiyarso, D., Gutierrez, V., Noordwijk, M. v., Creed, I. F., Pokorný, J., Gaveau, D. L. A., Spracklen, D. V., Tobella, A. B., Ilstedt, U., Teuling, A. J., Gebrehiwot, S. G., Sands, D. C., Muys, B., Verbist, B., . . . Sullivan, C. A. (2017). Trees, forests and water : Cool insights for a hot world. Global Environmental Change-human and Policy Dimensions, 43, 51-61. https://doi.org/(https://doi.org/10.1016/j.gloenvcha.2017.01.002)

[45] Environment, N. G. D. o. P. a. (2023). Determining stream order. https://water.nsw.gov.au/__data/assets/pdf_file/0020/511553/determining-strahler-stream-order-fact-sheet.pdf

[46] Eswaran, H., & Reich, P. (2003). Global desertification vulnerability map. United States Department of Agriculture, Natural Resources Conservation Service, Washington, DC, USA. http://www. nrcs. usda. gov/wps/portal/nrcs/detail/soils/use. (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/use/worldsoils/?cid=nrcs142p2_054003)

[47] Eyles, R. (1977). Changes in drainage networks since 1820, Southern Tablelands, NSW.

Australian Geographer, 13(6), 377-386. https://doi.org/(https://doi.org/10.1080/00049187708702716)

[48] Farber, S., & Turner, R. (2014). Changes in the global value of ecosystem services. Global Environmental. https://doi.org/https://doi.org/10.1016/j.gloenvcha.2014.04.002

[49] Ferguson, R. S., & Lovell, S. T. (2014). Permaculture for agroecology: design, movement, practice, and worldview. A review. Agronomy for sustainable development, 34(2), 251-274. https://doi.org/(https://doi.org/10.1007/s13593-013-0181-6)

[50] Fiebrig, I., Zikeli, S., Bach, S., & Gruber, S. (2020). Perspectives on permaculture for commercial farming: aspirations and realities. Organic Agriculture, 10(3), 379-394. https://doi.org/(https://doi.org/10.1007/s13165-020-00281-8).

[51] Finney, D. M., White, C. M., & Kaye, J. P. (2016). Biomass production and carbon/nitrogen ratio influence ecosystem services from cover crop mixtures. Agronomy Journal, 108(1), 39-52. https://doi.org/https://doi.org/10.2134/agronj15.0182

[52] Fischer, J., Zerger, A., Gibbons, P., Stott, J., & Law, B. S. (2010). Tree decline and the future of Australian farmland biodiversity. Proceedings of the National Academy of Sciences, 107(45), 19597-19602. https://doi.org/https://doi.org/10.1073/pnas.1008476107

[53] Freund, M., Henley, B. J., Karoly, D. J., Allen, K. J., & Baker, P. J. (2017). Multi-century cool-and warm-season rainfall reconstructions for Australia's major climatic regions. Climate of the Past, 13(12), 1751-1770. https://doi.org/(https://doi.org/10.5194/cp-13-1751-2017)

[54] Gaba, S., Reboud, X., & Fried, G. (2016). Agroecology and conservation of weed diversity in agricultural lands. In (Vol. 163, pp. 351-354): Taylor & Francis.

[55] Geno, L. M., & Geno, B. J. (2001). Polyculture production: principles, benefits and risks of multiple cropping land management systems for Australia: a report for the rural industries research and development corporation. Rural Industries Research and Development Corporation.

[56] Giller, K. E., Hijbeek, R., Andersson, J. A., & Sumberg, J. (2021). Regenerative agriculture: An agronomic perspective. Outlook on Agriculture, 50(1), 13-25. https://doi.org/https://doi.org/10.1177/0030727021998063

[57] Gosnell, H., Gill, N., & Voyer, M. (2019). Transformational adaptation on the farm: Processes of change and persistence in transitions to ‘climate-smart’regenerative agriculture. Global Environmental Change, 59, 101965. https://doi.org/https://doi.org/10.1016/j.gloenvcha.2019.101965

[58] Götsch, E. (1995). Break-through in agriculture. AS-PTA Rio de Janeiro.

http://nossacasa.net/nossosriachos/agroecologia/wp-content/uploads/sites/9/2020/10/1995a_Ernest_Gotsch.pdf

[59] Grace, P., Post, W., Godwin, D., Bryceson, K., Truscott, M., & Hennessy, K. J. (2019). Soil carbon dynamics in relation to soil surface management and cropping systems in Australian agroecosystems. Management of carbon sequestration in soil, 175-193.

[60] Harlan, J. R., & deWet, J. M. (1965). Some thoughts about weeds. Economic botany, 19(1), 16-24. (http://www.jstor.org/stable/4252561)

[61] Hathaway, M. D. (2016). Agroecology and permaculture: addressing key ecological problems by rethinking and redesigning agricultural systems. Journal of Environmental Studies and Sciences, 6(2), 239-250. https://doi.org/(https://doi.org/10.1007/s13412-015-0254-8)

[62] Hesslerová, P., Pokorný, J., Huryna, H., & Harper, D. (2019). Wetlands and forests regulate climate via evapotranspiration. In Wetlands: Ecosystem Services, Restoration and Wise Use (pp. 63-93). Springer. https://doi.org/(https://doi.org/10.1007/978-3-030-14861-4_4)

[63] Hill, S. B., & Ramsay, J. (1977). Weeds as indicators of soil conditions. The McDonald Journal, 38(6), 8-12. (https://www.researchgate.net/profile/Jennifer-Ramsay/publication/265487256_Weeds_as_Indicators_Of_Soil_Conditions/links/551aec2f0cf2bb7540786db9/Weeds-as-Indicators-Of-Soil-Conditions.pdf)

[64] Howard, S. A. (1943). An Agricultural Testament. In: JSTOR.

[65] Hurditch, W. (2015). Sustainable water and energy management in Australia's farming landscapes. WIT Transactions on Ecology and the Environment, 200, 329-341. https://doi.org/(https://doi.org/10.2495/WS150281)

[66] Ikerd, J. (2021). THE ECONOMIC PAMPHLETEER: Realities of regenerative agriculture. Journal of Agriculture, Food Systems, and Community Development, 10(2), 7–10-17–10. https://doi.org/DOI: https://doi.org/10.5304/jafscd.2021.102.001

[67] Jackson, R. B., Lajtha, K., Crow, S. E., Hugelius, G., Kramer, M. G., & Piñeiro, G. (2017). The ecology of soil carbon: pools, vulnerabilities, and biotic and abiotic controls. Annual Review of Ecology, Evolution, and Systematics, 48(1), 419-445. https://doi.org/https://doi.org/10.1146/annurev-ecolsys-112414-054234

[68] Jehne, W. (2019). Regenerate Earth. Visited on: http://www. globalcoolingearth. org. (http://nzbiocharltd.co.nz/resources/Regenerate-Earth-Paper-Walter-Jehne%20%281%29.pdf)

[69] Johnson, D., Ellington, J., & Eaton, W. (2015). Development of soil microbial

communities for promoting sustainability in agriculture and a global carbon fix (2167-9843). (https://peerj.com/preprints/789v1.pdf)

[70] Johnson, D. C., Teague, R., Apfelbaum, S., Thompson, R., & Byck, P. (2022). Adaptive multi-paddock grazing management's influence on soil food web community structure for: increasing pasture forage production, soil organic carbon, and reducing soil respiration rates in southeastern USA ranches. PeerJ, 10, e13750. https://doi.org/(https://doi.org/10.7717/peerj.13750)

[71] Jones, C. (2010). Soil carbon-can it save agriculture's bacon? The Permaculture Research Institute. (http://amazingcarbon.com/PDF/JONES-SoilCarbon&AgricultureREVISED(18May10).pdf)

[72] Jones, C. (2018). Light farming: restoring carbon, organic nitrogen and biodiversity to agricultural soils. Agriculture, s Innovative Minds Symposium,. Wichita, Kansas, USA,

[73] Junk, W. J., An, S., Finlayson, C., Gopal, B., Květ, J., Mitchell, S. A., Mitsch, W. J., & Robarts, R. D. (2013). Current state of knowledge regarding the world's wetlands and their future under global climate change: a synthesis. Aquatic sciences, 75(1), 151-167. (https://pure.mpg.de/rest/items/item_1737912/component/file_1737913/content)

[74] Kell, W. V. (1938). Strip cropping. (https://naldc.nal.usda.gov/download/IND43893616/PDF)

[75] Kikuchi, Y., Sasaki, Y., Yoshino, H., Okahashi, J., Yoshida, M., & Inaba, N. (2014). Local visions of the landscape: participatory photographic survey of the world heritage site, the rice terraces of the Philippine Cordilleras. Landscape Research, 39(4), 387-401. https://doi.org/(https://doi.org/10.1080/01426397.2012.761189)

[76] King, F. C. (1951). The weed problem-a new approach. The weed problem-a new approach.

[77] Kravčík, M., Gabriš, P., & Kravčíková, D. (2020). Projects Implemented and Lessons Learnt from the New Water Paradigm. In W. Leal Filho, J. Luetz, & D. Ayal (Eds.), Handbook of Climate Change Management: Research, Leadership, Transformation (pp. 1-46). Springer International Publishing. https://doi.org/10.1007/978-3-030-22759-3_132-1

[78] Kravčík, M., Pokorný, J., Kohutiar, J., Kovác, M., & Tóth, E. (2007). The New Water Paradigm-Water for the Recovery of the Climate. Krupa Print, Žilina. http://www.waterparadigm.org

[79] Krebs, J., & Bach, S. (2018). Permaculture—Scientific evidence of principles for the agroecological design of farming systems. Sustainability, 10(9), 3218. https://doi.org/

https://doi.org/10.3390/su10093218

[80] Lal, R. (2020a). Managing soils for resolving the conflict between agriculture and nature: The hard talk. European Journal of Soil Science, 71(1), 1-9. https://doi.org/https://doi-org.ezproxy.scu.edu.au/10.1111/ejss.12857

[81] Lal, R. (2020b). Regenerative agriculture for food and climate. Journal of Soil and Water Conservation, 75(5), 123A-124A. https://doi.org/https://doi.org/10.2489/jswc.2020.0620A

[82] Lange, M., Eisenhauer, N., Sierra, C. A., Bessler, H., Engels, C., Griffiths, R. I., Mellado-Vázquez, P. G., Malik, A. A., Roy, J., & Scheu, S. (2015). Plant diversity increases soil microbial activity and soil carbon storage. Nature Communications, 6(1), 6707. https://doi.org/https://doi.org/10.1038/ncomms7707

[83] Lhotsky, J. (1835). A Journey from Sydney to the Australian Alps, undertaken in the months of January, February, and March, 1834. Being an account of the geographical & natural relation of the country traversed, its aborigines, etc.[With a map and with MS. material inserted.]. Sydney;[by commission at R. Ackerman's depository: London]. (https://nla.gov.au/nla.obj-495608964/view?partId=nla.obj-509632507#page/n8/mode/1up)

[84] Lichtenberg, E. (2019). Conservation and the environment in US farm legislation. EuroChoices, 18(1), 49-55. https://doi.org/(https://doi.org/10.1111/1746-692X.12214)

[85] Lowdermilk, W. C. (1948). Conquest of the land through seven thousand years. US Department of Agriculture, Soil Conservation Service.

[86] MacLaren, C., Storkey, J., Menegat, A., Metcalfe, H., & Dehnen-Schmutz, K. (2020). An ecological future for weed science to sustain crop production and the environment. A review. Agronomy for sustainable development, 40(4), 1-29. https://doi.org/(https://doi.org/10.1007/s13593-020-00631-6)

[87] Mahaut, L., Cheptou, P.-O., Fried, G., Munoz, F., Storkey, J., Vasseur, F., Violle, C., & Bretagnolle, F. (2020). Weeds: against the rules? Trends in plant science, 25(11), 1107-1116. https://doi.org/(https://doi.org/10.1016/j.tplants.2020.05.013)

[88] Makarieva, A. M., & Gorshkov, V. G. (2007). Biotic pump of atmospheric moisture as driver of the hydrological cycle on land. Hydrology and earth system sciences, 11(2), 1013-1033. https://doi.org/(https://doi.org/10.5194/hess-11-1013-2007)

[89] Makarieva, A. M., Gorshkov, V. G., Sheil, D., Nobre, A. D., Bunyard, P., & Li, B.-L. (2014). Why does air passage over forest yield more rain? Examining the coupling between rainfall, pressure, and atmospheric moisture content. Journal of

Hydrometeorology, 15(1), 411-426. https://doi.org/(https://doi.org/10.1175/JHM-D-12-0190.1)

[90] Mao, J., Nierop, K. G. J., Dekker, S. C., Dekker, L. W., & Chen, B. (2018). Understanding the mechanisms of soil water repellency from nanoscale to ecosystem scale: a review. Journal of Soils and Sediments, 19, 171-185. https://doi.org/(https://doi.org/10.1007/s11368-018-2195-9)

[91] Marinova, D., & Bogueva, D. (2022). Food and Environmental Emergency. In Food in a Planetary Emergency (pp. 37-55). Springer.

[92] Marshall, N. A., Friedel, M., van Klinken, R. D., & Grice, A. C. (2011). Considering the social dimension of invasive species: the case of buffel grass. Environmental science & policy, 14(3), 327-338. https://doi.org/(https://doi.org/10.1016/j.envsci.2010.10.005)

[93] Massy, C. (2020). Call of the reed warbler: A new agriculture–a new earth. Univ. of Queensland Press. https://www.regenwa.com/wp-content/uploads/2020/04/Call-of-the-Reed-Warbler.-A-new-Agriculture-a-New-Earth.pdf

[94] Massy, C. J. (2013). Transforming the earth: A study in the change of agricultural mindscapes. https://openresearch-repository.anu.edu.au/bitstream/1885/115203/2/b35577204-Massy_Charles.pdf

[95] McCaman, J. L. (1994). Weeds and why they grow.

[96] McCloskey, G., Wasson, R., Boggs, G., & Douglas, M. (2016). Timing and causes of gully erosion in the riparian zone of the semi-arid tropical Victoria River, Australia: Management implications. Geomorphology, 266, 96-104. https://doi.org/(https://doi.org/10.1016/j.geomorph.2016.05.009)

[97] Meteorology, A. G. B. o. (2001). Map of Climate Zones of Australia http://www.bom.gov.au/climate/how/newproducts/images/zones.shtml

[98] Millar, J. (1995). Pasture doctor: a guide to diagnosing problems in pastures. Inkata Press.

[99] Mitchell, T. L. (1839). Three expeditions into the interior of Eastern Australia: with descriptions of the recently explored region of Australia Felix, and of the present colony of New South Wales. Libraries Board of South Australia. (https://adc.library.usyd.edu.au/data-2/mitthre.pdf)

[100] Mollison, B. (1979). Permaculture two: Practical design and further theory in permanent agriculture. Stanley, Australia: Tagari Books.

[101] Mollison, B. (1988). Permaculture: a designer's manual. Permaculture: a designer's manual.

[102] Mollison, B. C., & Holmgren, D. (1978). Permaculture 1: a perennial agricultural system

for human settlements. Transworld Publishers.

[103] Morris, G. D. (2004). Sustaining national water supplies by understanding the dynamic capacity that humus has to increase soil water-storage capacity. The University of Sydney. http://www.biodynamics2024.com.au/wp-content/uploads/2009/04/PlainOldDirt.pdf

[104] Myhre, G., Samset, B. H., Hodnebrog, Ø., Andrews, T., Boucher, O., Faluvegi, G., Fläschner, D., Forster, P., Kasoar, M., & Kharin, V. (2018). Sensible heat has significantly affected the global hydrological cycle over the historical period. Nature Communications, 9(1), 1-9. https://doi.org/https://doi.org/10.1038/s41467-018-04307-4

[105] Nara, K., Nakaya, H., Wu, B., Zhou, Z., & Hogetsu, T. (2003). Underground primary succession of ectomycorrhizal fungi in a volcanic desert on Mount Fuji. New Phytologist, 159(3), 743-756. https://doi.org/ https://doi.org/10.1046/j.1469-8137.2003.00844.x

[106] Neal, A. L., Bacq-Labreuil, A., Zhang, X., Clark, I. M., Coleman, K., Mooney, S. J., Ritz, K., & Crawford, J. W. (2020). Soil as an extended composite phenotype of the microbial metagenome. Scientific reports, 10(1), 1-16. https://doi.org/https://doi.org/10.1038/s41598-020-67631-0

[107] Nicholls, N. (2010). Local and remote causes of the southern Australian autumn-winter rainfall decline, 1958–2007. Climate dynamics, 34(6), 835-845. https://doi.org/https://doi.org/10.1007/s00382-009-0527-6

[108] Niles, S. A. (1982). Style and function in Inca agricultural works near Cuzco. Ñawpa Pacha, 20(1), 163-182. https://doi.org/https://doi.org/10.1179/naw.1982.20.1.009

[109] Norman, L., Brinkerhoff, F., Gwilliam, E., Guertin, D., Callegary, J., Goodrich, D., Nagler, P., & Gray, F. (2016). Hydrologic response of streams restored with check dams in the Chiricahua Mountains, Arizona. River Research and Applications, 32(4), 519-527. https://doi.org/https://doi.org/10.1002/rra.2895

[110] Norman, L. M. (2022). Commentary: Dryland Watershed Restoration With Rock Detention Structures: A Nature-Based Solution to Mitigate Drought, Erosion, Flooding, and Atmospheric Carbon. Frontiers in Environmental Science, 242. https://doi.org/https://doi.org/10.3389/fenvs.2021.679189

[111] Norris, D., & Andrews, P. (2010). Re-coupling the carbon and water cycles by Natural Sequence Farming. International journal of Water, 5(4), 386-395. https://doi.org/(https://doi.org/10.1504/IJW.2010.03873)

[112] NSW, S. C. S. (2023). The History of the Soil Conservation Service (https://www.scs.nsw.gov.au/about-the-soil-conservation-service/the-history-of-the-soil-conservation-service

[113] Numata, M., & Holzner, W. (1982). Biology and ecology of weeds. W. Junk.

[114] Nyagumbo, I., Nyamadzawo, G., & Madembo, C. (2019). Effects of three in-field water harvesting technologies on soil water content and maize yields in a semi-arid region of Zimbabwe. Agricultural water management, 216, 206-213. https://doi.org/https://doi.org/10.1016/j.agwat.2019.02.023

[115] Pearson, C. J. (2007). Regenerative, semiclosed systems: a priority for twenty-first-century agriculture. Bioscience, 57(5), 409-418. https://doi.org/https://doi.org/10.1641/B570506

[116] Pereira, P., Bogunovic, I., Muñoz-Rojas, M., & Brevik, E. C. (2018). Soil ecosystem services, sustainability, valuation and management. Current Opinion in Environmental Science & Health, 5, 7-13. https://doi.org/https://doi.org/10.1016/j.coesh.2017.12.003

[117] Pfeiffer, E. E. (1975). Weeds and What they Tell us. Rodale Press.

[118] Qualman, D. (2017). Agribusiness takes all: 90 years of Canadian net farm income. Darrin Qualman. (https://www.darrinqualman.com/canadian-net-farm-income/).

[119] Quinkenstein, A., Woellecke, J., Böhm, C., Grünewald, H., Freese, D., Schneider, B. U., & Hüttl, R. F. (2009). Ecological benefits of the alley cropping agroforestry system in sensitive regions of Europe. Environmental science & policy, 12(8), 1112-1121. https://doi.org/https://doi.org/10.1016/j.envsci.2009.08.008

[120] QUT. (2022). Unlocking the true value of organic soil amendments. https://research.qut.edu.au/cab/projects/unlocking-the-true-value-of-organic-soil-amendments/

[121] Ramesh, K., Matloob, A., Aslam, F., Florentine, S. K., & Chauhan, B. S. (2017). Weeds in a changing climate: vulnerabilities, consequences, and implications for future weed management. Frontiers in plant science, 8, 95. https://doi.org/https://doi.org/10.3389/fpls.2017.00095

[122] Revitt, D. M., Ellis, J. B., & Lundy, L. (2017). Assessing the impact of swales on receiving water quality. Urban water journal, 14(8), 839-845. https://doi.org/https://doi.org/10.1080/1573062X.2017.1279187

[123] Reynard, E., & Estoppey, E. (2021). The Lavaux World Heritage terraced vineyard. In Landscapes and Landforms of Switzerland (pp. 111-121). Springer. https://doi.org/(https://doi.org/10.1007/978-3-030-43203-4_8)

[124] SA, R. S. (2011). Farm dams: a guide to siting, design, construction and management on eyre peninsula. (https://www.scribd.com/document/378811797/Farm-Dams-Fact)

[125] Sakurai, K., Kawazu, H., Kono, Y., Yanagisawa, M., Le, V. T., Le, Q. T., Dangthisong, N.,

& Chau, T. N. (2004). Impact of agricultural practices on slope land soil properties of the mountainous region of northern Vietnam: a case study in bac Ha District, Lao Cai Province. Japanese Journal of Southeast Asian Studies, 41(4), 503-518. https://doi.org/(https://doi.org/10.20495/tak.41.4_503)

[126] Sanford, A. W. (2011). Ethics, Narrative, and Agriculture: Transforming Agricultural Practice through Ecological Imagination. Journal of agricultural and environmental ethics, 24(3), 283-303. https://doi.org/10.1007/s10806-010-9246-6

[127] Scavo, A., & Mauromicale, G. (2020). Integrated weed management in herbaceous field crops. Agronomy, 10(4), 466. https://doi.org/https://doi.org/10.3390/agronomy10040466

[128] Schneider, T., O'Gorman, P. A., & Levine, X. J. (2010). Water vapor and the dynamics of climate changes. Reviews of Geophysics, 48(3). https://doi.org/https://doi.org/10.1029/2009RG000302

[129] Scott, J., Webber, B., Murphy, H., Ota, N., Kriticos, D., & Loechel, B. (2014). AdaptNRM Weeds and climate change: supporting weed management adaptation. In: CSIRO, Canberra, www. AdaptNRM. org.

[130] Seidel, R., Moyer, J., Nichols, K., & Bhosekar, V. (2017). Studies on long-term performance of organic and conventional cropping systems in Pennsylvania. Organic Agriculture, 7(1), 53-61. (https://link.springer.com/article/10.1007/s13165-015-0145-z)

[131] Selim, M. (2019). A review of advantages, disadvantages and challenges of crop rotations. Egyptian Journal of Agronomy, 41(1), 1-10. https://doi.org/(https://doi.org/10.21608/agro.2019.6606.1139).

[132] Sheil, D., & Murdiyarso, D. (2009). How forests attract rain: an examination of a new hypothesis. Bioscience, 59(4), 341-347. https://doi.org/https://doi.org/10.1525/bio.2009.59.4.12

[133] Shilton, P., Norman, P., Stone, B., & Carey, B. (2015). Soil conservation guidelines for Queensland. Department of Science, Information Technology and Innovation. https://www.publications.qld.gov.au/dataset/soil-conservation-guidelines/resource/8850848a-11c0-43b9-9463-855cd1cc943b

[134] Sime, G. (2018). A Discourse Analysis of Postmodern Agricultural Research and Extension Models: An Epistemological Perspectivism. Journal of Experimental Agriculture International,, 27(3), 1-11. https://doi.org/https://doi.org/10.9734/JEAI/2018/26180

[135] Singh, D., Sale, P., & Routley, R. (2005). Increasing phosphorus supply in subsurface soil in northern Australia: Rationale for deep placement and the effects with various crops.

Plant and Soil, 269(1), 35-44. https://doi.org/(https://doi.org/10.1007/s11104-004-2475-6)

[136] Skinner, R. H., & Dell, C. J. (2016). Yield and soil carbon sequestration in grazed pastures sown with two or five forage species. Crop Science, 56(4), 2035-2044. https://doi.org/https://doi.org/10.2135/cropsci2015.11.0711

[137] Smith, C., & Dawborn, K. (2011). Permaculture pioneers: Stories from the new frontier. In: Daylesford, Vic: Holmgren Design Service.

[138] Sokol, N. W., & Bradford, M. A. (2019). Microbial formation of stable soil carbon is more efficient from belowground than aboveground input. Nature Geoscience, 12(1), 46-53. https://doi.org/https://doi.org/10.1038/s41561-018-0258-6

[139] Steffen, W., Vertessy, R., Dean, A., Hughes, L., Bambrick, H., Gergis, J., & Rice, M. (2018). Deluge and drought: Australia's water security in a changing climate. (https://apo.org.au/node/202981)

[140] Sturt, C. (1834). Two expeditions into the interior of Southern Australia: during the years 1828, 1829, 1830 and 1831 with observations on... New South Wales (Vol. 2). Smith.

[141] Sušnik, J., Masia, S., Kravčík, M., Pokorný, J., & Hesslerová, P. (2022). Costs and benefits of landscape-based water retention measures as nature-based solutions to mitigating climate impacts in eastern Germany, Czech Republic, and Slovakia. Land Degradation & Development, 33(16), 3074-3087. https://doi.org/https://doi.org/10.1002/ldr.4373

[142] Tardio, G., Mickovski, S. B., Rauch, H. P., Fernandes, J. P., & Acharya, M. S. (2018). The use of bamboo for erosion control and slope stabilization: Soil bioengineering works. Bamboo: Current and Future Prospects, 105. https://doi.org/(http://dx.doi.org/10.5772/intechopen.75626)

[143] Tautges, N. E., Chiartas, J. L., Gaudin, A. C., O'Geen, A. T., Herrera, I., & Scow, K. M. (2019). Deep soil inventories reveal that impacts of cover crops and compost on soil carbon sequestration differ in surface and subsurface soils. Global Change Biology, 25(11), 3753-3766. https://doi.org/ https://doi.org/10.1111/gcb.14762

[144] Teague, R., & Barnes, M. (2017). Grazing management that regenerates ecosystem function and grazingland livelihoods. African Journal of Range & Forage Science, 34(2), 77-86. https://doi.org/https://doi.org/10.2989/10220119.2017.1334706

[145] Teague, W. R., Apfelbaum, S., Lal, R., Kreuter, U. P., Rowntree, J., Davies, C., Conser, R., Rasmussen, M., Hatfield, J., & Wang, T. (2016). The role of ruminants in reducing agriculture's carbon footprint in North America. Journal of Soil and Water Conservation, 71(2), 156-164. https://practicalfarmers.org/wp-content/uploads/2018/10/Teague-et-al-

2016-JSWC-Role-of-ruminants-in-reducing-agricultures-C-footprint-in-North-America.pdf

[146] Thompson, S. C. G., & Barton, M. A. (1994). Ecocentric and anthropocentric attitudes toward the environment. Journal of environmental Psychology, 14(2), 149-157. https://doi.org/https://doi.org/10.1016/S0272-4944(05)80168-9

[147] Trognitz, F., Hackl, E., Widhalm, S., & Sessitsch, A. (2016). The role of plant–microbiome interactions in weed establishment and control. FEMS Microbiology Ecology, 92(10). https://doi.org/https://doi.org/10.1093/femsec/fiw138

[148] Van Vlack, C. H., & Clapp, L. E. (1940). Contour farming for soil and water conservation. Bull. Iowa agric. Exp. Stn., 323-335. (https://www.bestfilebook.com/pdf/contour-farming-for-soil-and-water-conservation/)

[149] Varotto, M., Ferrarese, F., & Pappalardo, S. E. (2019). Italian Terraced Landscapes: The Shapes and the Trends. In World Terraced Landscapes: History, Environment, Quality of Life (pp. 27-43). Springer.

[150] Vogt, J., Safriel, U., Von Maltitz, G., Sokona, Y., Zougmore, R., Bastin, G., & Hill, J. (2011). Monitoring and assessment of land degradation and desertification: towards new conceptual and integrated approaches. Land Degradation & Development, 22(2), 150-165. https://doi.org/(https://doi.org/10.1002/ldr.1075)

[151] Walters, C. (1991). Weeds: control without poisons. Acres USA.

[152] Ward, M. S., Simmonds, J. S., Reside, A. E., Watson, J. E., Rhodes, J. R., Possingham, H. P., Trezise, J., Fletcher, R., File, L., & Taylor, M. (2019). Lots of loss with little scrutiny: The attrition of habitat critical for threatened species in Australia. Conservation Science and Practice, 1(11), e117. https://doi.org/(https://doi.org/10.1111/csp2.117)

[153] Weersink, A., & Pannell, D. (2017). Payments versus direct controls for environmental externalities in agriculture. In Oxford Research Encyclopedia of Environmental Science. https://doi.org/https://doi.org/10.1093/acrefore/9780199389414.013.520

[154] Weisser, W. W., Roscher, C., Meyer, S. T., Ebeling, A., Luo, G., Allan, E., Beßler, H., Barnard, R. L., Buchmann, N., & Buscot, F. (2017). Biodiversity effects on ecosystem functioning in a 15-year grassland experiment: Patterns, mechanisms, and open questions. Basic and applied ecology, 23, 1-73. https://doi.org/https://doi.org/10.1016/j.baae.2017.06.002

[155] Wichelns, D. (2015). Achieving water and food security in 2050: outlook, policies, and investments. Agriculture, 5(2), 188-220. https://doi.org/https://doi.org/10.3390/agriculture5020188

[156] Williams, J. (2010). The principles of Natural Sequence Farming. International journal of Water, 5(4), 396-400. https://doi.org/(https://doi.org/10.1504/IJW.2010.038731)

[157] Williams, M. (2015). Earth, air, fire and water: distinguishing human impacts from natural desertification in South Australia. Transactions of the Royal Society of South Australia, 139(1), 9-18. https://doi.org/(http://dx.doi.org/10.1080/03721426.2015.1035214)

[158] Williamson, C. J., Kupc, A., Axisa, D., Bilsback, K. R., Bui, T., Campuzano-Jost, P., Dollner, M., Froyd, K. D., Hodshire, A. L., Jimenez, J. L., Kodros, J. K., Luo, G., Murphy, D. M., Nault, B. A., Ray, E. A., Weinzierl, B., Wilson, J. C., Yu, F., Yu, P., . . . Brock, C. A. (2019). A large source of cloud condensation nuclei from new particle formation in the tropics. Nature, 574(7778), 399-403. https://doi.org/10.1038/s41586-019-1638-9

[159] Wilson, M. (2006). Willows: weeds of retention. (https://www.nsfarming.com/Media/P10.%20Micheal%20Wilson%20NSFpaperv2-Willows%20final%20doc.pdf)

[160] Wolka, K., Mulder, J., & Biazin, B. (2018). Effects of soil and water conservation techniques on crop yield, runoff and soil loss in Sub-Saharan Africa: A review. Agricultural water management, 207, 67-79. https://doi.org/(https://doi.org/10.1016/j.agwat.2018.05.016)

[161] Yeomans, A. (2005). Priority One-Together We Can Beat Global Warming by Allan J. 2005. Internet Source-http://www. yeomansplow. com. au/priority-one-contents. htm.

[162] Yeomans, A. Y. (1971). The City Forest: The Keyline Plan for the Human Environment. Keyline Pub. Pty. https://repositorio.ufsc.br/bitstream/handle/123456789/206490/1971%20Percival%20Alfred%20Yeomans%20-%20The%20City%20Forest.pdf?sequence=1

[163] Yeomans, K. B., & Yeomans, P. A. (1993). Water for every farm. Keyline Designs.

[164] Yeomans, P. A. (1958). The challenge of landscape: the development and practice of Keyline. Keyline Pub. Pty. https://repositorio.ufsc.br/bitstream/handle/123456789/206486/1958%20Percival%20Alfred%20Yeomans%20the-challenge-of-landscape.pdf?sequence=1