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IMPLICATIONS OF INDENSATION FOR AGRICULTURE

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Abstract

The general functioning of the soil-plant system is considered by way of the relationships between plants and soil microbes. Water and nutrients are addressed, focusing on the supply of water and production of new nutrients essential for the system to develop and survive. The discussion addresses implications for human population levels, and constraints to research and implementation that currently limit the development of sustainable agricultural systems.

Introduction

Indensation represents the accession of liquid water from the atmosphere other than by dew or rainfall (Tunstall 2009a). Plants are effective indensers, and indensation provides an explanation for occurrences with plants that were previously inexplicable. However, it also accounts for occurrences that have been otherwise explained. These explanations require reconsideration as, while some are sound, others range from plausible, through tenuous, to highly imaginative.

The considerations address system function by way of relationships between plants, atmosphere, mineral soil, and soil microbes, as these determine whether the system improves or declines. Positive feedbacks are central, with development occurring where gains promote further gains. The system declines where losses promote further losses.

Through positive feedbacks vegetation development promotes further development (Tunstall 2008a). Vegetation degradation does not necessarily promote further degradation as the positive feedbacks can promote self repair. However, at a critical level of decline feedbacks within the system can promote further degradation. The degradation applies to the entire soil-plant-atmosphere system as the system develops through interrelationships between components. Severe degradation is manifest as desertification which, while previously restricted to particular regions, is now occurring globally with global warming.

The focus is on agriculture as agriculture is the prime cause of desertification.

Basic System Function

Most coarsely and without taking account of indensation, plants produce carbohydrates through photosynthesis using energy from solar radiation, CO_2 from the atmosphere, and water and nutrients from the soil. The carbohydrates are variously converted into other organic compounds to build the plant infrastructure and reproduce. Plant development can be, and is, limited by each of these factors, where the limiting effect of one factor depends on the levels of the others.

Gaining atmospheric CO_2 involves an inevitable loss of water. As rainfall is intermittent and the input of radiation regular, there can be extended periods when water limits plant development. This limitation is mitigated to some extent by soil water storage making water available to plants during periods without rain, but water still generally limits the development of most vegetation for significant periods.

Indensation makes water available to plants during periods without rain similarly to soil water storage. However, indensation does not remove water as a limitation as it depends on atmospheric conditions. Hot, dry conditions are unsuitable for indensation. Indensation provides an additional source of water to plants, and its supply can be more regular than with rainfall, but it does not remove the limitation of water availability. Survival on indensed water alone essentially requires purpose designed plant structures, as with cacti, but the level of vegetation development is then strongly water limited limited.

The evolutionary development of indensation can be charted by the response of plant leaves to the perfield. The leaves of grass trees (*Xanthorrhoea sp.*) have no response. With the ancient but more recent cycads (*Cycas revoluta*) the response is reasonably low and restricted to a specific orientation of the leaf. Flat leaves such as acacia phyllodes typically only respond when the flat surface is vertical, and this limits the interception of solar radiation. The more recently developed V shaped leaves respond when horizontal, but the leaf must be right way up. The most recent development appears to be leaf forms that respond when in motion, as when blown by the wind (*Themeda triandra*).

The evolutionary considerations given by Tunstall (2008b) apply to microbes as well as plants and other organisms, and are manifest in the development of the total system. Water indensed by plants must be stored prior to use as most would be acquired at night when photosynthesis cannot occur. Some plants store most, if not all of the indensed water within their structures, as with cacti, succulents, and bottle trees. However, most plants use the soil for storage and this makes the water available to others, particularly soil microorganisms. Just as microbes have evolved to use plant residues they would have evolved to take advantage of water indensed by plants.

The relationships between plants and microbes show a wide range of associations from strongly pathogenic to strongly symbiotic. Just as pathogenic associations degrade vegetation development, symbiotic associations promote it. The potential for the development of vegetation is much greater with the development of symbiotic relationships between plants and microbes than without them.

The best documented symbiotic relationships between plants and microbes involves nitrogen fixation wherein plants obtain around 98% of their essential nitrogen via bacteria. There would be extremely little vegetation without bacteria. However, the role of microbes in supplying other nutrients to plants is poorly documented, except perhaps for phosphorus. Phosphorus must be in particular forms to be taken up by plants (H2PO4, HPO4) and those forms are rare to absent in rocks. Plants obtain phosphorus through microbes converting mineral forms of phosphorus into plant available forms.

All elements must be in specific forms to be available to plants where the required forms are usually achieved through prior incorporation into organic matter. Bacteria are primarily responsible for the acquisition of nutrients from minerals, and hence for their incorporation into organic matter. Also, it will likely be found that a considerable number of elements are provided through bacteria utilising orbitally rearranged monatomic elements (ORMES) (Tunstall 2009b).

The development of symbiotic fungal associations with roots is also becoming well documented but with the implications being largely unclear. Protection against pathogenic microbes has always been identified, and is undoubtedly important. Other benefits involve access to nutrients. The fine mycelia provide a highly energy efficient means of exploiting the soil volume for nutrients and transporting to them to plant roots. While bacteria can provide nutrients their small size and limited mobility limit access to them by plants.

While some soil bacteria obtain energy from non-organic sources most utilise plant residues. All of the energy used by fungi derives from plants. The system is driven by energy provided by plants through conversion of solar radiation into organic compounds.

The focus above is on the provision of new nutrients as the system can only develop given an ongoing supply. This contrasts with most considerations of soil microorganisms which focus on recycling. The focus on recycling arises because the provision of new nutrients is small compared to the turnover of nutrients in recycling: most microbial activity involves recycling. However, as recycling inevitably involves losses the provision of new nutrients is essential to the system surviving, let alone developing.

With symbiotic/mutualistic associations the development of the system is greater than would be given by the sum of the component parts because of positive feedbacks and interactions. An example positive feedback is plants promoting microbes by providing food, and microbes providing nutrients to plants. The greater the plant development the greater the microbes, and the greater the microbes the greater the nutrient provision to plants.

The nature of interactions is best illustrated by microbes investing around 10% of the energy provided by plants into infrastructure by way of soil organic matter. Some forms of organic matter produced by microbes are resistant to breakdown by microbes, and are therefore unavailable to them as food. The benefit of the investment to the microbes arises indirectly through improvements in soil structure that promote aeration and the storage of water and nutrients. These improvements promote the growth of plants and thereby increase the food available to the microbes.

The compounding gains are seen in the effect of appropriate forms of organic matter on soil properties. A little soil organic matter gives large improvements when in an appropriate form. The gains in soil aeration and water and nutrient retention from the addition of organic matter to mineral soil are much greater than given by the sum of their separate contributions. The initial investment in microbes by plants improves the general condition of the soil for everything.

Overall the positive feedbacks increase the amount of resource available to, and hence incorporated into, vegetation. At my current level of knowledge microorganisms are involved in the provision of nutrients in plant available forms, the transport of the nutrients to plants, and the improvements in soil physical conditions for plant roots. The enhanced supply of water through indensation likely arises through plants only, but it benefits both plants and microbes. The importance of ORMES is likely the provision of elements essential for plant growth that are scarce or absent in the mineral soil.

Wheat Crops

Water aside, the main requirement for a good wheat crop in Australia is early planting. For yields to be high the crop must mature under cool conditions.

The importance of cool conditions has been attributed to physiological aging. The increase in the rate of aging as conditions become hot reduces the time available for grain filling. While the rate of grain filling primarily depends on photosynthesis by the flag leaf, and the rate of photosynthesis depends on leaf age as well as atmospheric conditions, the rate of the filling is roughly constant from seed set to the onset of plant senescence.   The time available for grain filling is important, and the rate of plant aging determines that time

Indensation provides an additional means by which cooler conditions can promote crop yields. Cooler conditions promote indensation due to higher humidity, and thereby increase the amount of water available for plant growth during the grain filling period.

Application of mineral nitrogen to wheat crops is usual and has been promoted by the premium now paid for high protein grain. Such nitrogen application is central to agriculture and has been thought to build the soil organic matter. However, recent observations on long established cropping systems have shown that high doses of mineral nitrogen decrease the soil organic matter (Khan, 2007; Mulvaney, 2009)

This decrease in soil organic matter with application of mineral nitrogen should have been expected as nitrogen applications have long been known to decrease the root-shoot ratio. This has presented a dilemma for many farmers as nitrogen applications can decrease yields, and even cause crops to fail. Nitrogen application increase yields where water is readily available but can decrease yields where water is limiting, largely because the reduced root growth decreases access to water while the increased shoot growth increases its rate of use.

The above addresses the short term impact of nitrogen doses on plants. The long term impacts derive though direct effects on soil microbes as well as indirect effects through plants. Nitrogen applications promote the breakdown of soil organic mater by microbes by changing the carbon-nitrogen ratio nitrogen, and thereby decrease the level of soil organic matter. Additionally, the reduction in plant root growth reduces the input of organic matter into the soil which promotes further decrease in soil organic matter. This is compounded by disruption of the symbiotic relationship between plants and microbes as plants have no need to promote microbes when nutrients are readily directly available. As the support by plants for microbes declines so does the microbial investment in soil infrastructure by way of the production of organic compounds resistant to breakdown.

Chain of Ponds

With Natural Sequence Farming (NSF) the beneficial effect of chain of ponds (COP) has been explained by way of landscape hydration. Retention of water in the system through subsurface irrigation is seen as hydrating the soils, with vegetation developing in response to the increased availability of water. The prime focus is on raising stream levels and slowing the rate of stream flow to promote seepage of water from streams through the surrounding alluvial flats.

An obvious issue with this explanation is that the extent of hydration can only extend as far as the subsurface irrigation. The hydration is then restricted to flats adjacent to streams which is typically a small part of any landscape. However, some procedures use constructed channels to divert water from streams across slopes to irrigate somewhat higher parts of the landscape. Even then, as the process involves redistributing water from streams, it can never hydrate an entire landscape. The NSF representation of COP can only be applied to small parts of landscapes and, given the need for reliable stream flows, it can only be applied to few areas in Australia.

The harvesting of water from streams associated with the NSF representation of COP raises significant social issues as the water belongs to the State. Licenses are required to use such water but these requirements have been ignored.

The NSF representation of COP is not what is occurring in the historic situation illustrated by Cooper (Tunstall 2009c).   Historically water in the streams largely derived from percolation through the soil where the percolation largely derived from water indensed by vegetation. That is, COP developed through hydration of the landscape by vegetation, not by vegetation developing in response to water from COP as suggested with NSF.

Significance aspects of vegetation hydrating the landscape are that the entire landscape is hydrated and not small parts associated with streams, and the process is applicable to all of Australia. The social significance is that the indensed water is owned by the landholder and can be used without a need for permits. Ownership of water only transfers to the State when it enters a well defined aquifer such as stream or groundwater system.

The water aspects of NSF have received attention because of declining flows in rivers, however, NSF incorporates other elements relating to vegetation management. The maintenance a good cover of green vegetation and lack of soil disturbance are as with cell grazing, but there is an additional requirement for a diverse mix of plant species. This appears to be important in maintaining fertility by way of a full complement of nutrients.

Cell Grazing

Benefits from cell grazing have essentially been attributed to lack of disturbance to the soil. The development of soil organic matter associated with prolific root development and complex microbial populations increases the nutrients available to plants. It also increases aeration, percolation, and the soil water storage capacity.

The large increase in plant production has been mainly attributed to the increase in soil water storage capacity. However, the increase in soil water storage capacity due to soil organic matter has usually been greatly overestimated and alone cannot account for the increased plant production. Moreover, while the potential gains in plant water use from an increase in soil water storage capacity are appreciable they need not be realised. For example, Bell et al. (2001) observed that the amount of rainfall used by degraded and improved grassland was the same despite large differences in vegetation development and soil organic matter. The realised situation can differ markedly from theoretical predictions based on laboratory measurements of soil properties as factors additional to soil water storage capacity affect the outcome.

Indensation provides an explanation for the large production increase that can be obtained with cell grazing. Through indensation the maintenance of a good cover of green vegetation increases the water available for plant growth. However, the gains also arise from improvements to the soil associated with development of microbes and hence soil organic matter, where these are promoted by the additional water provided by indensation. Lack of soil disturbance is a key factor promoting the gains.

Control of grazing is central to achieving the benefits as indensation requires a cover of green vegetation. Maturation and senescence greatly reduce or eliminate green leaf hence plants must be kept in a vegetative stage. This can be achieved by the removal of developing flowers through regular grazing. Pasture productivity is highest when plants are maintained in the vegetative growth stage by grazing but pastures should never be overgrazed.

Temperature is identified as the prime determinant of phasic development of plants (e.g. Tunstall 2009d), but the effect of preventing flower development indicates that it is not the sole factor. Similarly, severe droughting has been shown to stop physiological development in grasses with the period of stress not contributing to plant age.

Phasic development patterns of pasture plants limit grazing in many areas of Australia. In northern Australia grasses become tall and rank if ungrazed, and of little value for grazing. Most benefit is obtained from small patches where concentrated grazing early in the wet season maintains the grasses in a vegetative growth phase. Cattle continue to graze the same patch while most areas are effectively ungrazed because plants in grazed patches have higher nutrition than where allowed to mature and senesce.

In alpine areas such as Omeo the rate of physiological development of plants in spring is too rapid for grazing by livestock to significantly affect their development. ‘Improved’ pastures there are characterised by a massive amount of quality herbage being available for a few months during spring and little useful herbage being available at other times.

Pasture Cropping

Pasture cropping provides the same benefits as cell grazing but the management is more complex. The critical requirements for maintenance of green vegetative cover and lack of soil disturbance are met using a combination of perennial pasture plants and an annual crop. Grazing is used to facilitate the establishment of the crop. Implementations combine a winter annual crop with a mix of mainly summer growing perennial pasture plants.

Yeomans Keyline System

Implementation of the Yeomans Keyline System (YKS) involves diverting water from gullies to ridges where this redistribution increases the retention of rainfall within the system. However, it also involves the maintenance of a good cover of green vegetation by planting trees as well as pasture. This maintenance of green vegetation provides for hydration of the landscape through indensation.

The Wallace plough is used in implementing the Yeomans System to divert water from gullies to ridges. However, it also fractures compacted soils and therefore improves water infiltration everywhere. Critically, the fracturing is achieved without disrupting the soil profile so that microbial processes are promoted by improved aeration and water availability.

The Wallace plow provides a means of rapidly repairing degraded landscapes. The land is sequentially ploughed at increasing depths where this removes hard pans and increases the depth of development of soil organic matter.

Traditional Chinese

The benefits appear to be as indicated previously (Tunstall 2008c) and center on the maintenance of as much green vegetation as possible, and the retention of nutrients through recycling. The development of green vegetation promotes indensation and the retention of ORMES. However, scaling issues associated with the periodic occurrence of patches of bare soil are uncertain by way of importance and the nature of effects.

Shifting Agriculture

Shifting agriculture essentially relies on natural processes to achieve sustainability, and is successful given a sufficiently long rotation period. Indensation and soil microbial activity are central elements to the recovery of the land following cropping.

Perma Culture

Perma culture is designed to operate as a natural system in providing a continuous cover of diverse plants. Moreover, soil disturbance is minimal. Perma culture likely maximises indensation and can be completely sustainable. The only issues relate to productivity by way of the type, amount, and timing. Modern agriculture has evolved around bulk produce that can be readily stored and transported, such as grains. Produce from perma culture does not address these needs, and comparatively requires large labour inputs per unit production. The issues are therefore social rather than relating to the sustainability of the system.

Microbial Applications

Research into the use of mychorrhizal bacteria was prominent in Australia during the mid 1900s when combined plantings of grasses and legumes were promoted for pastures. Grasses provided the bulk by way of cellulose production while legumes boosted nutrition. Subclover was the main legume in temperate areas and Stylos in the tropics.

The early use of microbes focused on selecting bacteria for inoculating mychorrhiza, with individual strains being selected for each plant species and location. While this approach continues the greatest benefits derive from applications of diverse populations of bacteria. The gains are greatest where all parts of the system are promoted rather than a particular component considered important. The general requirement with microbes appears to be the same as for cell grazing and pasture cropping; activities should address the total system rather than focus on a particular component considered to be important.

The selection of particular strains of bacteria for inoculating plant species represents the same approach as applying mineral fertilisers. The focus is on addressing one component of the system considered limiting rather than the entire system. Such promotion of a particular component almost invariably provides immediate gains, often appreciable. However, it also almost invariably produces long term losses compared with approaches that develop the entire system.

Concepts behind the development of appropriate bacterial treatments appear similar to those for vegetation development. The requirement is for a diverse mixture of compatible species that incorporate the capacity to cope with and flourish under widely fluctuating conditions.

Discussion

Broad scale livestock grazing has been globally disastrous having previously caused regional desertification in Europe, Africa and Asia, with these now being joined by regions in South America and Australia. Controlled grazing systems, such as Yeomans Keyline System and Cell Grazing, can provide sustainable solutions.

Small plot production systems such as permaculture can address requirements for the sustainable production of crop produce but have low productivity. Broad scale cropping systems address productivity but not the quality of food or sustainability of production. Pasture cropping is currently the only viable system in Australian croplands but that has very limited implementation. While a potential exists for the development of other sustainable cropping systems, particularly in more mesic environments, it can only be realised given major changes to how agriculture is approached. The constraints currently addressed in the development of agricultural systems are finance, markets and machinery when biological constraints should be paramount.

Human populations have expanded with broadscale farming, particularly cropping. While projections of a global sustainable human population differ greatly they increased appreciably during the ‘green revolution’ given expected production gains from mineral fertilisers and plant breeding. However, the expected gains have not been fully realised, and productivity is declining were gains from the new practices had been appreciable. Given the consequences of an increasing population and decreasing agricultural production (Tunstall 2009e) changes are being introduced in attempts to again boost productivity, as with the use of chemical herbicides and genetic engineering.

The bare soil, mineral fertiliser and monospecific crops associated with broadscale cropping promote desertification, where bare soil can arise through ploughing or the use of herbicides. While the green revolution initially faded, the bubble represented by that approach to agriculture has now burst with global warming.

Expectations for human populations are now usually based on maintaining productivity and increasing the land under production. However, with global warming arising through desertification the current levels of productivity cannot be sustained with existing practices. Productivity will inevitably decline and, if unchecked, the decline will be dramatic. Moreover, increasing the amount of land under such agriculture will promote global warming and therefore exacerbate the decline. Existing human populations cannot be maintained in the future if current agricultural practices are continued.

The decline in productivity with desertification can be rapid with systems effectively crashing. However, as different areas crash at different times the net global effect will be a smooth decline. The rate of that decline, and the depth to which it plunges, depend on management actions.

The analytical approach used here is variously described using terms such as integrated, holistic, and systems. However, it is basically ecological in considering interrelationships between biological components of the system and the physical environment. It differs from many ecological studies in taking account of processes rather than simply addressing the dynamics of biota[1].

Ecology is fundamentally multidisciplinary in addressing interrelationships between biological and physical processes. The approach is now unusual in science as the current focus is on narrow disciplines, with ecology being seen either as a form of biology, which ignores the constraints imposed by physical processes, or the simple combining of two disciplines. For example, an ex Chief of a CSIRO Division stated that ecology is the combination of physics and plant physiology where this ignores the existence of interrelationships between plants and other biological components of communities. With this engineering approach, which has become the norm in agriculture, few aspects of agricultural systems that were addressed here would be considered.

Multidisciplinary Divisions did exist in CSIRO, as with the ex Land Research, but these were progressively stripped of their multidisciplinary assets through reviews involving academics. The imposition of a disciplinary structure, together with the enforcement of no duplication or overlap of research activities between groups, has neutered the relevance of research in most organisations addressing the environment. Recent changes directed at redressing the situation in CSIRO serve little purpose as they operate at a high administrative level that has little relevance for the conduct of research.

Disciplinary approaches provide piecemeal solutions when addressing complex systems and so cannot resolve issues such as sustainability in agriculture and global warming.

Those addressing practical implementations in agriculture necessarily have a more holistic approach than most scientists, but they do not address all important aspects of the system. This

[1] Ecology is the relationship between organisms and their environment hence an analysis of relationships between organisms is technically not ecology. Environments cannot be addresses by reference to organisms alone.

deficiency arises through limitations in knowledge whereby few have detailed knowledge of system function. One consequence is that practical implementations typically address a specific requirement under a narrow range of conditions. Another is that explanations given as to how results are achieved are unreliable in usually being incorrect in at least one important aspect.

Indensation is undoubtedly important for vegetation development, and hence for the sustainability of agriculture. However, as indensation is produced by plants it is absent were land is denuded of vegetation. Sustainability depends on the maintenance of a continuous cover of green vegetation that can survive the inevitable fluctuations in weather as well as the impacts of land use.

As crop growth is usually limited by water the provision of water through indensation by plants is important for individual crops. However, as water use by vegetation can affect regional rainfall, indensation is critical to the long term viability of agriculture. The development and maintenance of vegetation is essential to the survival of mankind. Achieving the required development involves addressing processes in all components of the soil-plant system.

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