Biomimicry of Termite Engineering As Innovative Solution for Water and Soil Conservation

Amgad Elmahdi
[1] CSIRO land and water, Adelaide, PMB 2 Glen Osmond, SA 5064, Australia
E-mail: Amgad.Elmahdi@csiro.au

ABSTRACT

Nature has so much to offer to the current challenges facing societies and world, but unfortunately, societies tend to ignore or resort nature's offer/solution as the last option. Nowadays, world/mankind is facing a huge number of environmental problems. However, if researchers pay more attention to studying and understanding nature and nature's positive laws, it should help them play a critical role in overcoming and healing most of these problems. The main focus of this study is to present humanity and termites as design partners in the creation of a new dimension of water and soil conservation understanding. This understanding is based upon the likelihood that termites, as truly symbiotic detrivores, have developed optimal architecture and design for water and soil conservation in ecosystems over millions of years.

In this biomimicry concept study the objective is to present and discuss termite design for better water and soil management by government, industry and the public. Termites create environments that regulate and maintain near-constant moisture and temperature (green energy technology). Termites also create self-regulating energy systems that need no mechanical power for cooling and/or heating. In tropical climates, termites improve soil structure and moisture holding capacity and conserve water irrespective of changing environmental conditions. Thus, the focus/emerge question is can water and soil stakeholders mimic termite management systems in their bid to manage and sustain natural water and soil systems?

KEY WORDS: Biomimicry, Soil degradation and conversation, management, Termites, natural rehabilitations, Water infiltration and Ecosystem approach

INTRODUCTION

Nature has many lessons can teach but unfortunately, scientists and researchers are not paying attentions and ignore them at risk. World and particularly Australia is facing a huge number of environmental problems. However, by paying more attention to study and understanding nature and nature's positive laws, it should help scientists and researchers play a critical role in overcoming and healing most of these problems. The Gaia hypothesis; view the earth's atmosphere as circulatory system of biosphere (Margulis and Lovelock 1997).

Again, nature has many things still unrevealed and unknown therefore; there are need to continue observing and understanding this symbiotic planet. One known aspect of natures is the cycles of life-death-decay, then re-birth. This is the first lesson from the nature, is to understand the cycles of life-death-decay then new birth for everything but bacteria is 'programmed for death'. In Nature every dead organism is usually deposited and it serves as mulch in soil and food for other organism. The biomass that these organisms feed on consists of complex molecules, which are broken down into simpler inorganic molecules and soluble nutrients, which the organisms digest. Most decomposers are bacteria, actinomycetes, and fungi. Detritus feeders are often worms, invertebrates such as termites, springtails etc., and other animals such as crabs. In a natural environment, there is no waste. Everything is reused and is usually made into something of still greater value for the sustenance of life on Earth. Earth is covered mostly by water, only 20 percent is dry land.

Water is a key resource to sustain animal life. And, while only 50 litres of water per day per person is the recommended minimum for household use, 70 times as much is needed to meet the consumptive water use for producing human food for one person (SIWI, IFPRI, IUCN, IWMI 2005). Therefore, the sustain growth in human population requires even more water to be available (Elmahdi a. et al 2007). A reduction in water availability, soil erosion, and other water-related environmental problems are rapidly increasing in many parts of the world, including Australia. In the beginning the dry land consisted of lava, basalt, granite or other hardened materials. There was no soil on earth. Only life forces can make soil. But, there was no life because it takes soil to support life. In addition, water resources have the same amount now as there was when the earth was created. Furthermore, significant problems of water shortage and soil erosion are contributing to a growing nature crisis in many countries. This situation requires creative and natural solutions to achieve sustainable natural resource management. One of those promising natural solution is biomimicry of termites engineering for water and soil conservation.

This paper endeavours to focus on just two resources which are essential for our life on this planet, namely, water and soil, and the role termites can playing in sustaining such resources. In addition, trying to learn some lessons from the smallest and oldest animal in the world such termites and mimic termite's way/approach in managing water and soil conservation. This could be achieved in this paper by challenge to present the topic of biomimicry of termites for water and soil conservation.

Biomimicry Definitions and Issues

In general, Biomimicry is defined as a practice of taking ideas and concepts from nature and implementing them in any field such as engineering, design or computing – for example the development of machines that imitate birds, fish, flying insects or even plants. Although, this is not a novel concept, the concept of using and implementing ideas from nature for engineering objectives is very old. But recently, it has received a great fresh impulsion due to broad advances in science and technology. This is allowing to at least attempting approaching the sophistication of biological systems; this is linked with a growing interest in learning lessons from nature for engineering purposes, driven by recent civilizations increasing requirement for 'green' technological solutions to contemporary problems.

Biomimicry approach could help to decrease the environmental footprint of human and growth impacts. It is consider a crucial work, adding new and extremely valuable approach - biomimicry - to our research solutions of water and soil conservations. This paper attempt to introduce the topic of biomimicry of termites in water and soil conservation as envisaged by others scientists in other research fields.

It was reported by RMI Solution Newsletter 2003, biomimicry can be applied into buildings design in three fundamental processes: (1) to make stronger, tougher, self-assembling, and self-healing materials; (2) to use natural processes and forces to accomplish such basic building functions as heating and cooling; and (3) to produce resources, rather than drain them, by using/applying the biomimicry principles of zero waste and co-evolution. Biomimicry that incorporating natural concepts and processes into a more holistic design paradigm for water and soil conservations; tends to be not only environmentally sensitive, but also eminently practical and profitable.

Biomimicry makes sense; Mark Ayre (2004) claimed that for more than 3.8 billion years, nature has been facing with many of the same problems as now are struggling with and has developed the most efficient design solutions in order to survive. Biology has had to solve countless engineering problems since the appearance of life on Earth (Ball, 2001). The existing biological forms are impressed mankind by their abilities, and are inspired and stimulated by their designs, patterns and structures. Therefore, it is logical to perceive what nature has to offer in terms of water and soil conservations. Living organisms provide inspiration for innovations in many different fields such as termites and its behavior and ecological approach. Also, termites has the potential to improve the structure of crusted soils, including their capacity to limit soil compaction, increase soil porosity and improve the water infiltration in relation to water and soil conservation.

Biomimicry Concept and Applications

Biomimicry engineering is like any organism or function that it is imitating, highly multidisciplinary/interdisciplinary in nature, and embraces aspects related to materials, structures, mechanical properties, computing and control, design integration, optimization, functionality and cost effectiveness. Because of the incredible complexity of even just a single prokaryotic cell (not having a nucleus); it is still impossible and unnecessary to mimic or copy natures features exactly, but also because it often has totally different goals. For example make excellent fibers already; there is no need to imitate exactly spider silk. But the spider silk is manufacturing process used by the spider to give the silk such superb mechanical properties (Vollrath & Knight, 1999) (phenomenal tensile strength, impact load resistance etc.).

Consequently, the essential philosophy when attempting biomimicry engineering from biological examples is to formulate the ‘’analogy’’ at an appropriate level of abstraction (Benner, 2003). The chosen level of abstraction must allow capture of the desired characteristics of the biological system from which inspiration has been taken, whilst trying to avoid complexity in implementation as much as possible. Since, the biological system is invariably highly integrated and performs a number of different functions, thus it is not easy imitation processes.

According to Mark Ayre (2004) the area of biomimicry is very complex and difficult to be classified for two main reasons. The first reason is the number of biological systems from which to potentially draw inspiration is so massive and the second reason is the central principle of the discipline is multi-functionality system. However, Larson and Wertz, 1996, were able to classify biomimicry applications with clear overlapping between their classes: Structures and Materials; Mechanisms and Power; Behavior and Control; Sensors and Communication; Generational Biomimicry.

This study is mainly focus on the fourth category Behavior and Control. Finally, the question to answer is how can keep using water and soil resources while at the same time slowing and then reversing the damage to the environment? Is there perhaps a way that water and soil use could have a restorative effect? This study believes there is.

Water and Soil Conservations

Global warming and seasonal variations become a sign for future and many studies conducted on their impacts on future water and soil resources system. The literature indicates the coming years are facing more dry and hot weather. Hot dry weather has put a strain on water supplies/availability and soil fertility. Now, more than ever, it is important to use and conserve the water and soil systems more wisely. The first step in understanding and go on how to conserve water and soil systems; is to know where and how are used. As usual mankind often consider conserving the resources during the hard time and after facing vulnerable or shortage problem such as decreased the demand of that resource.

In general, conserving any resource leads to reduce of its waste that needs to be treated. The biggest problem has been gained the worldwide attentions is that most of farmland no longer has the organic matter and water supply for life and energy. According to Malcolm Beck (2004) now most farmland everywhere is down to 20% or less of what it should be. As recently as the 1940s, the organic content was all above 3% and closer to 5%. This represents a drop in organic content of between 70 to 90 percent in 60 years. In addition, erosion problem of topsoil is an increasing problem today. In turn the soil lost its organic matter, which lead to reduce the capacity of the soil to hold and catch water. The runoff carries the topsoil and goes into the rivers and streams. Then end up with barren unproductive sub soil. Although the earth covered by 74% water, fresh water shortages are worldwide problem due to all the water is salty except only 3% are fresh. About 75% to 90% of fresh water is used in irrigation. About 25% of irrigation needs could be stored and conserved if proper soil organic matter was sustained. Also storing water helps to manage water shortages.

The best and efficient place to store the annual rainfall and applied irrigation water is in the soil under mulch cover. The mulch layer of any organic material can protect the soil from exposure to the direct sun and drying winds which inturn reduced evaporation losses. It can hold heavy rains until soak in, this stops floods and soil erosion. If the water amounts are greater than the soil holding capacity, the good soil can filter and drip into aquifer system which can be used during dry periods as water banking/storage system. While water run off over the soil with carries the topsoil end up in the sea or catch in lakes or stream which in turn lost about 25% through evaporation and the soil particles are silts up the stream or the lake.

Under the mulch layer; termites can play important role by compacted the mulch and mix up the soil, in turn the microbes take over and compost the soil, which creates organic acids that help to dissolve minerals in the soil and then it all becomes healthy, rich fertile soil. Decaying organic matter on the soil surface saves water and builds fertile soil. Water and soil conservation is essential, but every little step helps to conserve. Introducing and implementing the concept of conservation will change the way water and soil utilised. Water source is finite; it means not have endless supply. With the growth rate for population and recommended produced food, it is now the time to consider preserving and conserving water and soil with restorative effect of environment.

Conserving water and soil helps to preserve environment; without doubt crops grown in rich organic soil require less water to grow (Donald L Sparks 2002). The nature help to save water because of the increased carbon dioxide release under crops or plants from mulch and organic rich soil, lead to the pores (stomata) on the plants leaves to open less and closed for longer. In turn, crops and plants transpire less water and draw less moisture from the soil while growing. Even though, organic rich soil can absorb and hold more water. Therefore, achieving water and soil conservations and building organic rich soil is very important role for future development and food security. Water and soil conservation need to be a way of life not just something for research and recommendation. It is the first step to keep the environment healthy and toward achieving sustainability in terms of water and soil health. Therefore, it is a task for the every day person who just likes to have access to the life sustaining resource of water and soil.

Termites Role in Water and Soil Conservation

Can termites help to restore the productive capacity of degraded soil and help in water conservation in order to have the ability to extend arable lands and sustain viable. In this section, the paper tries to review termite's capacity and role in soil and water conservations. Soil degradation, particularly crusting is a major agricultural problem BELNAP, J. (2006). The general reason behind this is the effect of extreme dry climatic conditions, over grazing, continuous cultivation and unsustainable management practices. All these factors could lead to spreading of bare and infertile soils.

The relation between degraded soil and water conservation is the crusted soil impedes water infiltration and root growth in turn lead to limit the use of lands for crops and animal production which lead to big economic problem and losses. Therefore, active restoration efforts of soil are needed and must be undertaken. Soil conservation and restoration is costly process but with some nature solution (biomimicry) such as using termites activities, could overcome degraded soil with less cost and more efficient environmental actions.

Termites are widespread and abundant in arid and semi arid region such Africa and Australia (French, 1986, and Lee and Wood, 1971). Even though termites are known as a major agricultural pests, but termites can also play an important role in recovering degraded ecosystems (French, 1988). Specifically, the burrowing and feeding activities of termites can be utilized to break up crusted soils and thereby counteract land degradation.

In addition, termites have the ability to reduce soil compaction, increase soil porosity and improve the water infiltration and retention capabilities of soils (Lee and Wood, 1971). Such conditions encourage root penetration, vegetative diversity, and the restoration of primary productivity, all prerequisites for food and livelihood security. According to Eric Roose (1996) four traditional water management methods and erosion control have defined to work on water that soil can not fully absorb as follows:

- Runoff harvesting (catching runoff for supplementary irrigation);
- Total absorption or infiltration;
- Runoff diversion (redirecting excess water);
- Runoff spreading (distribution of runoff energy).

Termites have the potential to make the first option more feasible see figure 1. This is a complex traditional method allowing recovery of degraded soils on broad loamy-sandy pediments. It combines harvesting runoff with concentrating mulch and available water, making use of termite activity. Termites can eat the organic matter, dig galleries, encourage penetration of runoff, distribute nutrients and finally improves infiltration and manure.

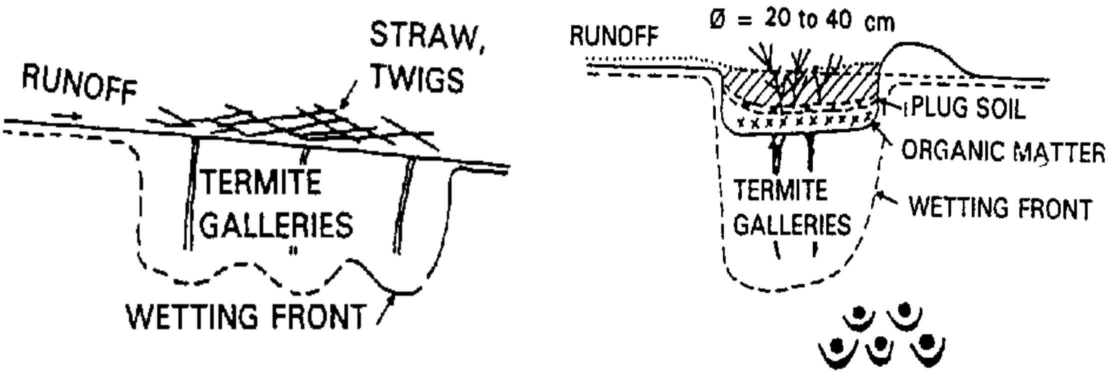

Figure 1: Harvesting and storing runoff from a semi-arid catchment (source: Roose 1989)

This example shows the flexibility in balancing the goals of conservation, sustainable use and agricultural production. Also, it explains as an example of allowed the negative impacts of termites to be turned into positive benefits for soil productivity. This could open the opportunity to consider conserving termite populations instead of eradicating them and stimulating their soil mixing capacities which would improve crusted soils. This is considered one of the ecologically solution which turn termites disaster (seasonal or successionally burrowing, excavation, and foraging) turned out to be a viable management option for soil degradation. Termites feeding upon mulch improved soil structure and water infiltration and thereby enhance nutrient release into soil from mulch. Managing any water and soil systems should be considered within environmental and biological conditions that using or applying such termite's concept to manage water and soil.

Relatively few studies have examined the relationship between termites and soil moisture contents (Watson, 1969; Sponsler and Appel, 1991; Holt, *et al.* 1996). Despite the fact that moisture is one of the key factors in attracting foraging termites, only a few studies have investigated the relationship between soil moisture and termite activity in soil environment. Termite distribution and survival depend on moisture, temperature and suitable food sources (Ettershank, and Whitford, 1980). The relationship of termites and moisture content of soil making up their immediate environment is basic in the design of sustainable ecosystems. It is well understood that different species of termites are characterised by different ecological conditions. Different termite species have different moisture and temperature requirements. Moisture is one of the most important factors in termite ecology. *C. acinaciformis* termites require relatively abundant and constant sources of moisture in soil, air and food (Leong *et al.* 1983, Ettershank and Whitford, 1980), while drywood termite require the amount of moisture retained in the wood. Termites require moisture, not only from the surrounding soil (relative humidity around 70 to 80%), but also from their food and air (Luscher, 1961; Watson, 1969; Grace, 1986). Alates are usually released by most termite species on humid (drizzling rain) and still days (Higa and Tamashiro, 1983).

A comprehensive study of such conditions would require a combined effort by entomologists and soil physics scientists. Different soils have different moisture holding capacities and these affect the availability of water for the plant, soil microorganisms, insects and other living organisms in soil (Luscher, 1961; Lee, and Wood, 1971). Termites and other soil dwelling insects are considered important biological agents that assist in maintaining soil water and organic nutrient for plants to grow (Elkins, *et al*. 1986).

Williams, (1934) and Van Genuchten and Th (1980) described the types of moisture present in soils as (i) hygroscopic water or moisture (a thin layer of water around the particle). Hygroscopic water is bound tightly by the soil solids at water potential values, lower than –3100 kPa. It is essentially non-liquid and moves primarily in the vapour form (ii) capillary water or capillary moisture (a film of water, which stretches, from particle to particle and remains in the upper layer of soil). Capillary water is held in the pores of capillary size and behaves according to the laws governing capillarity, such water includes most of the water available for plants to grow and is held with potential between –10 to-30 kPa (iii) gravitational water or hydrostatic moisture (excess water that flows downwards due to gravitational forces forming groundwater). Gravitational water of limited use to plants, because it is present in soil for a short time and also blocks soil aeration. However, gravitational water is the form in which most of soil leaching occurs.

Therefore, the quality of our life is connected to the quality of the soil and availability of water. The quality of the soil determines the quality of the air to breathe, water to drink and food to eat. Soil quality is determined by the amount of life, mineral, and energy it contains. Understanding and properly using the soil and water sources can solve the major problems facing mankind. World economy is connected to the water and soil.

Termite Biomimicry Engineering

There are huge database of natural solutions all around the world but to understand them and to access them, it is important to ask the right question and frame it in a way that biologists can response and understand for the environmental problem facing the world. For better understanding of biomimicry solutions for one of the engineering problems, scaling in water pipes. Biologist fined an easy solution for this problem as it causes millions of dollars of damage each year. It may not be immediately obvious that nature could offer a solution to this man-made problem, until considered that scaling as is simply the deposition of calcium carbonate onto the pipe. Knowing this now can look in nature's database for a creature that has learned to manipulate the landing and placement of calcium compounds. One creature particularly good at this is the deep-sea abalone. It forms a rock-hard shell by inducing calcium ions from surrounding seawater to fit exactly into its ionic blueprint Weiner, S. and P.M. Dove (2003). The shell doesn't keep on growing forever because when the shell is large enough, the abalone secretes specialized "stop" proteins that prevent further calcium ions from accreting. Thus, the suggested solution may be by coat water pipes with similar proteins (or mimic the shape of these proteins with another material), then calcium ions could no longer adhere; which lead to eliminate the problem of scaling and saving millions of dollars in chemicals and pipe replacements with a simple preventive solution.

According to Malcolm beck (2003), animal architecture is another biological database, can search for advanced materials and processes. From a whole-systems perspective, the African termite mound might be the supreme example of advanced animal architecture. It incorporates superb solutions to pervasive design problems (structural strength, elemental protection, ventilation, humidity control, etc.) that also face. So far at least one building has been highly successful in mimicking this sophisticated ventilation system. The Eastgate building in Harare, Zimbabwe, used the termites' innovative design to keep the building cool during the hottest days Benyus JM (2002). Using nature-inspired design to circulate fresh air into the building in place of noisy, electricity-hogging air-conditioners and fans improves comfort and cuts energy bills. This makes for happy building occupants who pay less and are more likely to renew lease agreements.

The most acknowledged master architect is termite of the creature world. No other insect or animal approaches the termite in the size and solidity of its building structure. The world's tallest non-human structures are built by Australian or African termites. If a human being were the size of an average termite, the relative size of a single termite nest is the equivalent of a 180 story building--almost 2000 feet high. It would easily be the tallest building in the world Abdoullaev Akhmad (2005).

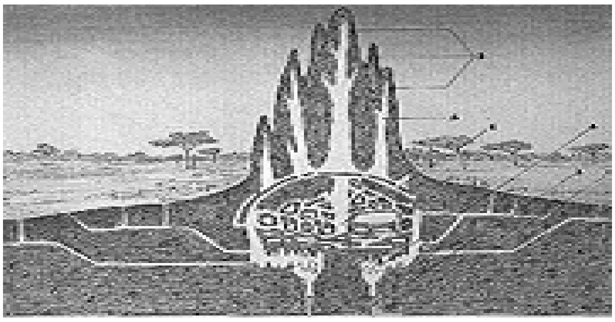

Figure 2 Termites mound (Source: lesson from nature, 1998)

In addition, one of the termites' architecture characteristic, are able to conserve water inside his mound and keep humidity. Obviously this knowledge is innate to the termite. Termites create environments that regulate and maintain near-constant moisture and temperature. Also termites create self-regulating energy systems that need no mechanical power for cooling and/or heating. Obviously raisin question is can we mimic termite management systems in our bid to manage and sustain our water and soil systems? Of course there are many unknown and not revealed mechanisms about termite's water management system inside his body, mound and community. There is need for further practical research to better understanding how this creature manage its system and be able to survive for more than 200 million years. This research paper open the potential for a new natural system that able to sustain managing world's water problem and it is considered as first attempt to introduce biomimicry concept to water mangers as it is critical as its innovations, design and operations.

Conclusion and lessons learnt

This paper presents water and soil worldwide problem and highlight the needs for water and soil conservations. Water and soil conservations lead to and considered as the first step to achieve sustainable water and soil management, which is a key to every society's to carry on development. Perhaps the most important lessons learned from this study, are that: significant soil degradation (compaction and crusting) could results from eradicating native termite pests rather than keep and use them, but this could sound for some scientists like ironically conclusion. The sensible outcome is introduced and use surface organic matter to feed termites promotes their capacity to regenerate crusted soils. This discussion demonstrates a natural and cost-effective way of using biological activity and mimic termites way of life to restore water and soil resources and seriously degraded and unproductive lands. Then, two questions need to be answered, how are these ideas turn into application and become reality? How can be translated from just ideas or possibilities into an end product to be easily used?.

Learning nature's secrets is very easy but to develop these secrets into conceptual solutions leap to biomimicry engineering solutions and products is very hard and will require a synthesis of fields. Engineers, architects, biologists, designers and economist all need to work together to both understand nature's innovations and collaboratively use these innovations to create healthy, agreeable environments. This cross disciplinary scientists is recommended research for future which could end up by the best use of each professional's experiences for achieving a common objective. The trials which scientists and researchers now faces are very interrelated in their scope which need working together, that could be an idealistic way for nowadays and future problems. The biomimicry approach goes beyond the level of an individual thinking or solution. Therefore, what should be done to present an overview of a whole system with practical application; should be seriously investigated through participatory processes including on-site experimentation and pilot project development which can lead to system working in harmony.

References

*Abdoullaev Akhmad(2005)*A Structure We Can Learn From (http://www.eng.hokudai.ac.jp/EGPSEE/newsletter/E-Vision_Vol-03_No-01.pdf) accessed October 2006

Ball, P. (2001). Lifes Lessons in Design. Nature, Vol. 409.

BELNAP, J. (2006) The potential roles of biological soil crusts in dryland hydrologic cycles. *Hydrological Processes,* 20**,** 3159-3178

Benner, S. A. (2003). Act Natural. Nature, Vol 421, 9.

Benyus JM (2002). *Biomimicry: Innovation Inspired by Nature.*Perennial, New York.

Calaby, J. H. and Gay, F. J. (1956). The distribution and biology of the genus *Coptotermes* (Isoptera) in Western Australia. *Australian Journal of Zoology* **4**: 19 –39.

Donald L Sparks, 2002, "Environmental Soil Chemistry" 2ND Edition Academic Press ISBN: 0126564469

Elkins, Z. N.; Sabol, G. V.; Ward, T. J. and Whitford, W. G. (1986). The influence of termites on hydrological characteristics of Chihuahuan desert ecosystem. *Oecologia* (Berlin). **68:** 521-528.

Elmahdi,A., H. Malano and T. Etchells (2007) Using System Dynamics to Model Water Reallocation, Environmentalist journal 2007 Vol 27,1. http://dx.doi.org/10.1007/s10669-007-9010-2)

Eric Roose 1996, "70 FAO SOILS BULLETIN" Soil Resources Management and Conservation Service Land and Water Development Division, FAO- Rome, 1996.

Ettershank, G. J. A. and Whitford W. G. (1980). Location of food sources by subterranean termites. *Environ. Entomol.* **9 (5):** 645 - 648.

Forschler, B. T. and Henderson, G. (1995). Subterranean termites behaviour reaction to water and survival of inundation: Implications for Field Populations. *Environ. Entomol.* **24** (6): 1592 – 1597.

French, J. R. J. (1986). Termites and their economic importance in Australia. *In*: Vinson, S.B., ed. Economic impact and control of social insects. New York: Praeger. pp. 103 - 129.
French, J. R. J. (1988a). Ecosystem-level experimentation in termite research. *Sociobiology*, **14**: 269 - 280.
French, J. R. J.; Turner, G. and Bradbury, J. F. (1976). Nitrogen fixation by bacteria from the hindgut of termites. *J. gen. Microbiol.* **95**: 202 - 206.
Gay, F. J.; Greaves, T.; Holdaway, F. G. and Wetherly, A. H. (1955). Standard laboratory colonies of termites for evaluating the resistance of timber, timber preservatives, and other materials to termite attack. Commonwealth Scientific and Industrial Research Organisation. Bull. No. 277, Melbourne, Australia pp.1-60.
Grace, J. K. (1986). A simple Humidity Chamber for maintaining subterranean termites (Isoptera: Rhinotermitidae) in laboratory. *Pan-Pacific Entomology*. **62 (3):** 221 223.
Higa, S. Y. and Tamashiro, M. (1983). Swarming of the Formosan subterranean termites, *Coptotermes formosanus* Shiraki in Hawaii (Isoptera: Rhinotermitidae). Proceedings, Hawaiian Entomological Society, 24 (2 & 3): 233-238.
Holt, J. A.; Bristow, K. L. and Mclvor, J. G. (1996). The effect of grazing pressure on soil animals and hydraulic properties of tow soils in semi-arid tropical Queensland. *Aust. J. Soil Res.* **34:** pp. 69 – 79.
Larson, W. J., Wertz, J. R. (1996). Space Mission Analysis and Design, Second Edition. Kluwer Academic Press, Space Technology Library.
Lee, K. E. and Wood, T. G. (1971). Termites and soils. Academic Press Publ., New York, pp. 225.
Leong, K. L. H.; Tamashiro, M.; Yates, J. and Su, N. Y. (1983). Microenvironmental Factors Regulating the Flight of *Coptotermes formosanus* Shiraki in Hawaii (Isoptera: Rhinotermitidae). *Proceedings, Hawaiian Entomological Society*. **24 (2 & 3):** 287 - 291.
Lesson from Nature 1998, http://www.tdrinc.com/natarch.html Accessed on 10 August 2006.
Luscher, M. (1961). Air-conditioned termite nests. *In Scientific American Journal*. **205 (1)**: 138 – 145.
Malcolm Mark 2003, "Air Pollution, Water Shortage & Soil Erosion— *A Different Farm Subsidy Approach* "**"(** http://www.malcolmbeck.com/books) Accessed on 25 August 2006.
Malcolm Mark 2004, **"**Our Future"(http://www.malcolmbeck.com/books) Accessed on 25 August 2006.
Mark Ayre 2004 " BIOMIMICRY – A REVIEW" ESTEC European Space Agency- issue 2 work package report.
RMI Solution newsletters 2003 (http://www.sustainablebusiness.com) Accessed on 20 August 2006.
SIWI, IFPRI, IUCN, IWMI (2005): Let it Reign: The New Water Paradigm for Global Food Security**,** Final Report to CSD-13, Stockholm International Water Institute, Stockholm.
Sponsler, R. C. and Appel, A. G. (1991). Temperature tolerance of the Formosan and Eastern subterranean termites (Isoptera: Rhinotermitidae). *J. Therm. Boil.* **16 (1):** 41- 44.
Van Genuchten and Th, M. (1980). A closed form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Science Society of America Journal.* **44:** 892 – 898.
Vollrath, F., Knight, D. P. (2001). Liquid Crystalline Spinning of Spider Silk. Nature, 410(6828):541-8.
Watson, J. P. (1969). Water movement in two termite mounds in Rhodesia. *J. of Ecology*, **57**: 441 – 451.
Weiner, S. and P.M. Dove (2003) An Overview of Biomineralization and the Problem of the Vital Effect. In *Biomineralization*. Eds. P.M. Dove, S. Weiner and J.J. De Yoreo. Mineralogical Society of America, Washington, D.C., v. 54, p. 1-31. [pdf]
Williams, O. L. (1934). Some factors limiting the distribution of termites. In C.A. Kofoid [ed.] Termite and termite control. Univ. Calif. Press Berkeley. Pp 42 - 49.