V. Venkatramanan · Shachi Shah
Ram Prasad *Editors*

Global Climate Change and Environmental Policy

Agriculture Perspectives

Springer

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Preface

Agriculture has come a long way since the agricultural revolution that took place 10000 years ago. The transformation from food gathering stage to food production provided human societies sufficient impetus for the meteoric growth of agriculture so much so that the agricultural activity is considered as the most important human enterprise that transformed global landscape. Technological advancement, industrial mode of production, and ever-increasing urge of the industrious cultivators engendered green revolution which aided in augmenting world agriculture production. Nevertheless, the last two centuries of the second millennium witnessed the human population growth from one billion to six billion, and currently, human population hovers around 7.7 billion. Human population growth indeed poses a couple of intriguing questions: Firstly, how to transform the present-day agriculture sector to achieve food and nutritional security through innovative solutions and technology adoption? Secondly, how to adapt the food system against human-induced climate change and checkmate the negative impacts of climate change on the agriculture production system? Since agriculture has immense mitigation potential and can substantially help in achieving our commitment to keep the increase in surface air temperature well below two-degree centigrade, it is pertinent to dovetail and harmonize the adaptation strategies and mitigation approaches of climate change in the agricultural policy-making. Agriculture policy-making through the lens of climate change must factor in ecological thinking and agricultural sustainability; vulnerability assessment of agro-based households; gender perspectives; policy measures to harmonize the demands of food production, feed and fodder production, and biofuel generation; strategies to improve the farmers or cultivators and other stakeholders through climate-smart adaptation practices like organic farming and agroforestry; capacitating the farmers in climate risk management, food value chain transformation through stakeholder-driven policy planning; and provision of agricultural inputs and services that include weather-based automated agro-advisories, crop insurance, and social security. The book endeavours to present the broad contours of global climate change, climate policy, and agriculture. The book targets the scientists, researchers, academicians, graduates, and doctoral students working on environmental science, environmental biology, and agricultural sciences. It also caters to the needs of policy-makers to frame policies on climate change, food security, agricultural resources, integrity of the food supply chain, and gender equity. We are deeply honoured to receive chapters from leading scientists and professors with rich experience and expertise in the field of global climate change, sustainable agriculture, and climate policy. The chapters provide an in-depth analysis of climate policy, sustainability of agroecosystem, vulnerability assessment of stakeholders, climate-smart farming, water footprint, policies to mitigate GHGs from agriculture and animal husbandry, agro-advisories, gender policy dimensions in agriculture, and biofuel policy.

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Ecological Thinking and Agricultural Sustainability

1

Anantanarayanan Raman

Abstract

Ecological or ecocentric thinking emerges from our appreciation of oneness with nature. Technocentric perception driven by scientific and empirical thinking builds on Charles Darwin's Theory of Evolution and Adam Smith's Wealth of the Nations. Those who can empathize with the ecocentric thinking can see the 'big' picture and understand the illusion of human mastery over nature. Nature has its precise mechanism of constant renewal and replenishment of materials, operating in a cyclical manner. When we humans thought that we have gained mastery over technology, we started interfering with the cycles of nature. Eventually, we damaged them to that extent that we have made them go berserk and turn linear. Consequently, we are currently facing stunning problems, such as pollution and other similar displeasing developments on Earth. In today's highly technocentric environment, where economic paradigms rule the roost, ecological paradigms are seen as 'primitive' and 'conservative'. To a few others, ecological paradigms appear daunting, challenging, and difficult to practice. The term 'sustainable development' refers to something more than, simply, growth. A change in the kind of growth is needed, a kind of development that is less material- and energy-intensive and more equitable in the distribution of its benefits. This emphasizes that changes are necessary and that the security, well-being, and the survival of the planet should be mutualistic with those changes. Sustainable development is not about giving priority to environmental concerns, but it is about incorporating environmental strengths into the economic system. Sustainability represents ideas of stability, equilibrium, and harmony with nature. Sustainable development is an attempt to reduce the politics in decision-making by artificially replacing conflict with consensus. Ecological thinking and its derivative ecological

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agriculture are practices that spin around simplicity and modesty. Aggressive dollar-driven thinking has no place in ecological thinking. Climate change, for example, is a problem created by us humans because of our badly thought-out and hasty practices of land use. If we realize this weakness and remedy it, then we still have hope to leave a cleaner and better world for the future generations of humans as well as other organisms that are as important as *H. sapiens*! We think that speed and rapid turnarounds of events are the norms of today. Is speed the root cause of present-day ecological–environmental malady, which has pushed us to think of sustainability?

Keywords
Agricultural sustainability · Ecological agriculture · Ecological thinking · Organic farming · Biodynamic farming · Natural farming · Permaculture · System of rice intensification

1.1 The Present Agricultural Scene

Over millennia, or perhaps for even more, our human ancestors lived hunting wild animals and gathering wild plants. Somewhere between 4500 and 10,000 years ago, the hunter-gatherer societies, in at least seven regions of the world, independently domesticated specific animal and plant species, which subsequently developed into agricultural economies.

One major human intervention of nature was the establishment of settlements, which involved the disturbance of soil and associated vegetation. Humans cleared vegetation to build residences. As long as humans remained hunter-gatherers, the disturbance to the natural environment was minimal, given the vastness of time. Once they moved to other localities establishing new settlements, the previously occupied sites regenerated back to near-natural near-original state. Such a recovery never eventuated — and could never happen — with humans settling permanently in specific places (Raman 2019). Clearing vegetation for building residences had its own other forms of consequences: The cleared sites encouraged aggressive, invasive plants to colonize and occupy vacant spaces due to either deliberate introductions or natural migrations. When humans moved from one place to another, they carried seeds of certain plants either deliberately or inadvertently and 'introduced' them into newer environments. One recent-time example would be the deliberate introduction of mango trees (*Mangifera indica*, Anacardiaceae) by humans into a new biogeographical locality—West Africa in 1824, from where this plant was spread to other warm regions of the world (Rey et al. 2004). Rivers are one other critical source that distributes seeds and vegetative material propagating them in new environments. Thus various reasons explain colonization of cleared areas by plants that do not usually occur in (or belong to) a particular region. The best examples for the natural colonization of plant material into the Indian landmass are the plant species that were domesticated by early Holocene 'farmers' of the Fertile

Crescent nearly 12,000 years ago. Those introduced plants, later, in 9000–10,000 years ago, stimulated the beginnings of systematic agriculture in southern Asia (Singh et al. 2016).

The transition from a foraging to a farming way of life was a major event in the evolutionary history of humankind. During this period, humans tried various techniques and primitive technology, thus making efforts to achieve better outcomes. Technology played a key role in enhancing agricultural capabilities of humans. The industrial revolution in Europe in the late seventeenth century ushered in new techniques and technologies that changed the global profile of agriculture. Since World War II, some nations have produced grains and other agricultural crops at around two-and-a-half times more than what they really required. Advancing technology and the urge to produce more in that period placed immense pressure on national economies to push agricultural production to greater levels. By responding to this economic pressure — by manipulating land and water to our advantage — we humans have inflicted substantial disruption to functional ecosystems on which the whole fabric of civilization depends. Through such behaviour we have pushed the world to a new, hitherto unperceived crisis. We have placed the Earth and its cycles of natural materials under stress, similar to the way we would strain a truck by simply loading it with 2–3 times more than its recommended load-carrying capacity. Such an action has resulted in what we today simplistically describe as 'environmental problems'. Some examples would be human population increase and consequently changed demographics, air and water pollution, overexploitation and depletion of natural materials such as plants and animals, and accumulation of non-degradable wastes, which turn into toxic over time.

Land came under severe stress in the last few decades (Fig. 1.1) (United Nations Environment Programme 1999). One highly serious issue that arose from unplanned utilization and overstressing of the environment is the widespread and unprecedented rate of recurrence of famines and droughts and eventual impoverishment in many parts of the world (The Brundtland Commission 1987). The Green Revolution was a concerted human effort in the 1960s to enhance agricultural productivity by altering several traditional practices, such as the use of high-yielding varieties, injudicious use of chemicals as fertilizers and pesticides, and heavy mechanization of farmland. The concept, developed by the American wheat geneticist Norman Borlaug, was trialled first in Mexico and subsequently followed religiously in many developing countries. The reality is that only 25% of the total land area of the Earth is suitable for farming activities. The remainder, which is either too dry or extremely harsh, experiences an adverse climate unsuitable for farming, or a permutation of these. Of this 25%, barely 3% is highly fertile, therefore productive land, 6% yields modestly, and the remaining 13% the output is poor. These are natural limiting factors to agriculture, but processes such as deforestation, desertification, and erosion — the results of mismanaged human activities — are further shrinking the area appropriate for agriculture. For example, of the *c.* 300 M ha of total land area in India, more than 50% is highly degraded and is beyond any redemption. One of the consequences of such mismanagement is the dramatic slowing down of per capita food production. Especially in these parts of the world, concern is mounting on the sustainability of

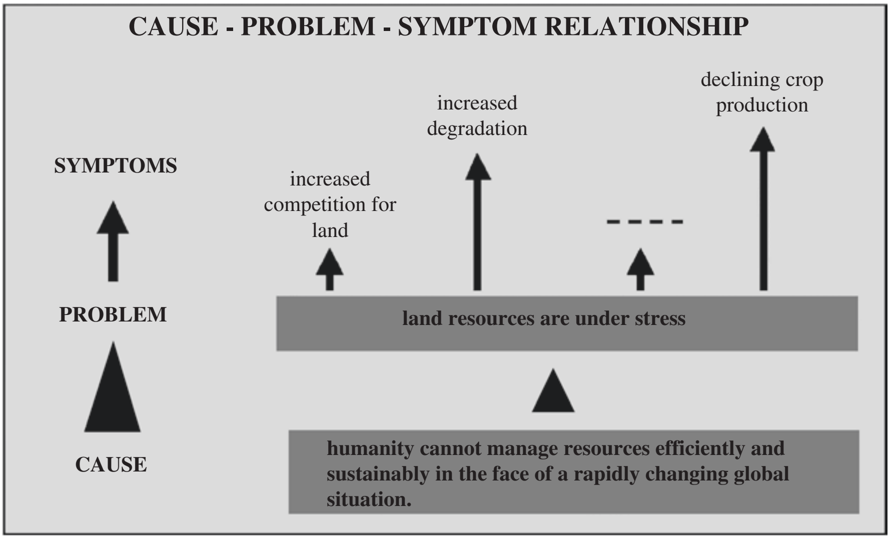


Fig. 1.1 Cause–problem–symptom relationship in stressed land-use pattern. (Adapted from: http://www.fao.org/docrep/004/).

'green revolution', because of continuing and accelerating degradation and destruction of the agricultural material base. In Africa, on an average, 10 times the value of plant nutrients are being removed annually from soil than that is being returned to soil. Overall, more than a third of the total land available on the Earth is being exploited for agriculture. Even in industrialized nations, for example the USA, soil is being eroded close to 20 times faster than it is being replaced (Hall and Hall 1993).

One possible solution for such crises lies in our ability to recognize farmland as an ecosystem: 'the agricultural ecosystem'. Such a perception alone can help us salvage whatever little materials (which will be, according to agricultural economists, 'resources') we still have with us, so that the world can sustain itself productively and usefully to humans and other organisms in the long run. Before the advent of inorganic fertilizers in the nineteenth century, farming depended solely on natural materials for nutrients. Will it be possible to combine the well-established indigenous practices with innovative methods such as new-crop breeds that will respond to low-chemical inputs? To achieve this, we will need models that will suit the circumstances of a particular region's economic and geographic profiles. Those models must also be sensitive to the social and environmental conditions at micro level (Woodwell 1990).

The Agriculture & Environment Conference of 1911 clarified that conventional agricultural practice has been the sole reason for the present environmental degradation (Edwards et al. 1993). The same conference also cautioned that traditional agricultural practices — some of which impress as sustainable — are rapidly disappearing and are replaced by farming practices that depend heavily on finite fossil fuels and associated technologies. To meet the needs for an effective and efficient management of soil, water, and other natural materials, can we aim for and work towards sustaining our production of food, fodder, fibre, and fuel on a per capita basis? Such a refined approach would minimize our dependency on petrochemical and other finite materials, currently used, overused, and abused in conventional agriculture, contributing to the improvement of the quality of soil, water, and other natural materials. Such an approach will improve per capita income and achieve greater equity in distribution. To achieve true sustainability, the human family needs to embrace an understanding in profound clarity that we, humans, are not beyond, but an integral part of nature. Embracing this understanding will involve changing the way we live and how we could organize ourselves sociologically and politically (Edwards et al. 1993; Schaller 1993).

1.2 Ecological Thinking

Ecological thinking arises out of our appreciation of our oneness with nature. Technocentric perception driven by scientific and empirical thinking emphasizes Darwin's Theory of Evolution, laced by the 'survival of the fittest' concept, which has led to human dominance perception. Those who can empathize with the ecological thinking can relate to the 'big' picture and also understand the illusion of human mastery over nature. In reality, we lose sight of the 'self' when we fail to perceive the wholesomeness of nature; also when we fail to perceive that, we are a mere component in the great scheme of things. We need to recognize that nature has its precise mechanism of constant renewal and replenishment of materials, which operates in a cyclical manner. When we humans thought that we have gained mastery — through science and its offspring, the technology — and have thus turned intensely technocentric, we started interfering with the cycles of nature. Eventually, we damaged them to go berserk in many instances and in some to turn linear. Consequent to this transformation from cyclicity to linearity, we are currently facing stunning problems, such as what we identify as 'pollution' and similar, not-so-desirable developments on the Earth. In today's technocentric environment, where economic paradigms rule the roost, ecological paradigms are seen as either 'difficult to practice' or 'primitive' or 'conservative'. To a few others, ecological paradigms appear daunting and challenging.

Movements endorsing ecological paradigms have been occurring throughout the world in different points of time. For example, in Australia, in the second half of the twentieth century, several thinkers have been contributing towards this end. For example, William Mollison and David Holmgren have created the unique 'nature–design system', which has come to stay as permaculture. Customarily, we see ecology as a hardcore science relating to the understanding of interactions of organisms with nature's factors. The offshoot of ecology — environmental science — speaks of strategies that would mitigate issues created by us humans (e.g. climate change). The value of perceiving ecology as a science-based empirical discourse, however, gradually came under close scrutiny in the middle decades of the twentieth century. The borders between ecology as a science and ecology as an art eventually turned obscure in the minds of several eminent ecologist-thinkers, who had previously practiced ecology as a pure, empirical science. This obscurity eventuated in the melding of philosophy on the one hand and ecology on the other (Naess 2008). However, the seeds for eco-philosophical thinking were indeed sown earlier by Aldo Leopold, an American ecologist-forester, who spoke of ‘land ethic’ in his *Sand County Almanac* (1949). Eco-philosophical thinking would be hard to perceive and compartmentalize, but when seen as a major advantage and emotional strength, it enables those that have succeeded to become more intensely creative and innovative. The obscure edges of eco-philosophical thinking — hereafter, ecological thinking — link the measurable scientific dimension of ecology and the immeasurable abstract (plus the partly measurable social) dimension of ecology. Ecological thinking as a distinct paradigm empowers humans with an ability to look within and outside. It is a powerful instrument that bridges empiricism and the abstract, thus providing intelligent and thinking humans a capacity to acquire a powerful vision.

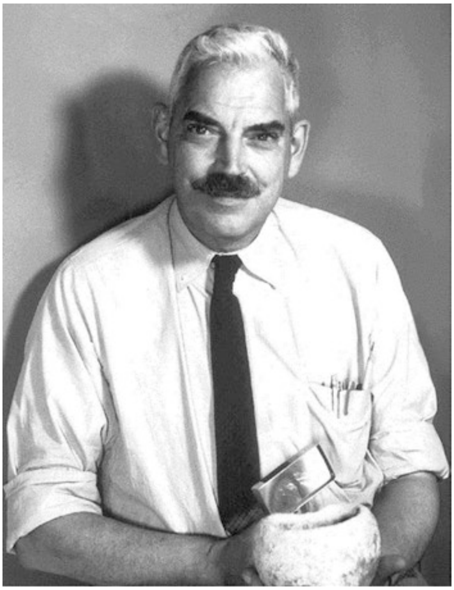
1.3 Development of Agriculture Through Millennia

The oldest evidence of organized farming practice comes from Jericho, presently in the Jordan valley. Circa 10,000 years ago, at the spring-fed oases of Jericho, strains of the eventual direction of civilization’s advances manifested. A few other smaller farming communities also flourished near the present city of Damascus and along the Euphrates. Over the next 1000 years in the Near East, domesticated plants and animals provided new and dependable food. These materials were considered dependable, because they could be stored for future needs and had the potential of ever-expanding yields. With the emergence of such agricultural societies, complex human social systems, namely villages, towns, cities, and city states, began to emerge. These systems exercised control over natural landscapes and gradually converted them into agricultural landscapes to feed human populations. It is noted that these modified landscapes produced grains for their populations only: an early presentation of what we today euphemistically call ‘self-sufficiency’.

The Near East and China provide early evidences for ‘organized’ farming. Agriculture, as a practice, seems to have evolved not once or twice, but several times in human history, since different animals and plants have been domesticated separately and independently in different segments of the world. These early agricultural societies expanded to adjacent regions and emerged as independent cultures, because of their confluence with the natural world around them. Against this natural and cultural growth of human societies, we need to contrast the agricultural landscapes of today, when we may realize how close we are, potentially, to the end of nature and its materials that are finite. Recent satellite pictures suggest that close to 20 M ha of rainforests are being degraded and lost annually in several of the tropical countries such as India, Cameroon, Myanmar, and Costa Rica. We also need to realize that the process of trying to transform natural landscapes into economically productive agricultural landscapes — accelerated after the industrial revolution in Europe — received further impetus with developments in agricultural machinery in the 1950s. However, we need to keep in focus that all of this was the continuation of a process that began 8000–10,000 years ago in Asia, and probably in the Western Hemisphere as well, when humans first domesticated animals and plants. Long before the European industrial revolution, humans have been trying to simplify their way of life. Some elementary technologies had been developed, perfected, and used thousands of years before (Valiulis 2014).

How did agriculture begin? What was the sequence in which plants and animals were first domesticated? Why only particular plants and animals were domesticated and not others? What were the wild ancestors of these domesticated plants and animals? Why did agriculture emerge in some regions of the world and not in others? Answers to such questions came from the investigations of the Russian biologist and geneticist Nikolai Vavilov (Portrait 1.1) and the American archaeologist Robert Braidwood (Portrait 1.2). Vavilov (1992), after extensive travels and collecting seed samples from different countries, drew the following conclusions: Because hundreds of varieties of ancient wheat existed in a small, isolated pocket on the Ethiopian Plateau, diversity in cultivated forms resulted from experimentation and deliberate human selection over time. The longer a crop is grown, the more extensively it gets used, and the greater the genetic variety that eventuates within a species. The greater its use by humans, the greater its resistance to pests and diseases. In essence, Vavilov indicated that the geographical area where a crop plant had the greatest diversity of forms would also be the place where it was first domesticated. By locating the centre of a crop's genetic diversity, we can know its epicentre. Vavilov argued that determination of a species' epicentre is critical for biological and genetic research on domesticated plants. However, we know today that the Vavilov theory has at least one flaw: domesticated organisms can, and did, originate in one geographical region and develop their diversity in another. The best examples that illustrate the

Portrait 1.1 Nikolay Vavilov (1887–1946). (Source: https://russiapedia.rt.com/prominent-russians/science-and-technology/nikolay-vavilov/)



Portrait 1.2 Robert Braidwood (1907–2003). (Source: https://msu-anthropology.github.io/deoa-ss16/braidwood/braidwood.html)

weakness in the Vavilov theory are cattle and pigs, which have a much broader distribution than their ranges where they were first domesticated. Another problem would be to locate the wild relative of the domesticated organism. Robert Braidwood studied the Fertile Crescent in the Near East (Braidwood et al. 1983) and indicated the following: (i) Archaeological evidence of the transition to an agricultural way of life in the Near East corresponded with the natural habitat zone for all potential domesticates. This argument was based on his findings that all the wild ancestors of seven major Near Eastern domesticates — barley, emmer, einkorn wheat, goats, sheep, pigs, and cattle — were sourced to the Zagros Mountains in Iraq. (ii) Discovery of the archaeological remains of a farming village at Jarmo dates back by 8000–9000 years ago. The Braidwood team reconstructed the climate when Jarmo flourished, based on sound scientific reasoning. That led to the assembly of evidence for the evolution of a very different way of life, from hunter-gatherer to settlements that later evolved into societies. (iii) Establishment of a human–cultural context is absolutely critical for understanding the evolution of agriculture.

The Vavilov theory based on the present-day plant-distribution patterns and the Braidwood theory based on the past and its reconstruction partly clarify issues of a complex jigsaw puzzle. However, their contributions have provoked several biologists, archaeologists, and historians to investigate the unresolved tiles of the of the gigantic jigsaw puzzle.

The Fertile Crescent in the Near East flourished and developed into a strong agricultural economy around 10,000 years ago. When fully formed *c*. 8000 years ago, it was already the home to plants and animals (e.g. barley, wheat, lentils, sheep, goat, cattle, and pigs) that would form the basis of many agricultural economies flourishing down the ages. In China, the earliest known farming settlements existed along the Yellow River in the north and along the Yangtze River in the south, well before agricultural development in the rest of the world. It is biological evidence rather than archaeological evidence that has contributed to the full picture of the agricultural evolution of Sub-Saharan Africa and Central America. Nonetheless, little is known about the evolution of farming practice in Southeast Asia and South America, although speculation continues on the root-crop agriculture in these regions. A satisfying explanation for the transformation of nomadic hunter-gatherers into organized farming communities is yet to be found. Scholars realize that they need to explain what was different about those particular hunter-gatherer societies where domestication of wild species occurred (Harlan 1992; Smith 1998).

Population growth has been one critical external factor that forced the hunter-gatherer groups to establish into settlements, drawn as they were towards an agricultural lifestyle. Modern interpretations partly reject the population theory and see overpopulation as one of the several unexplainable but interrelated factors. Modern interpretations value regional explanation more than a general, global explanation. Regional explanation more often tends to recognize the transition from nomadic hunting-gathering groups to established societies through a sequence of unresolved developmental puzzles. In the Fertile Crescent, for example, domestication of cereals and goats and the subsequent development of agricultural economies were part of a complex and long-term transformation. This can be better appreciated when we compare and contrast the Levantine Corridor (the narrow strip of land between the Mediterranean Sea and the North African desert), Southern Sahara, and the eastern segment of North America. In all these three regions, seed plants, and not root crops, were domesticated (e.g. barley, einkorn wheat, and emmer wheat in Levantine Corridor; millet, sorghum, and African rice in the southern Sahara; marsh elder, sunflower, chenopods, and squash in eastern North America); wild ancestors of these domesticates were key food items before their domestication; the regional human societies had developed efficient technologies for harvesting and processing seeds; the people who domesticated these plants lived in relatively large, permanent communities, leading a sedentary way of life; and the seed plants in question were cultivated near lakes and rivers ensuring predictable water supply.

1.4 Modern Agriculture: Evolved on the Principles of Technology, Economics, and Management

Agriculture is presently driven by the urge to produce more in small land spaces. Technology's ever-widening capabilities have enabled us to go crazy with this initiative. In the last few decades, we have witnessed tremendous success. Countries that have not been self-insufficient in food production in the 1950s have achieved self-sufficiency in the 1970s and have even started exporting grains. Norman Borlaug sketched the grand design for this landmark achievement. Many developing nations adopted that design and realized self-sufficiency in agriculture. Many developed nations captured the Borlaug design and improved their agriculture significantly and substantially. In numerous instances, nations achieved remarkable monetary gains, as they combined technical and chemical innovations with entrepreneurial opportunism. However, two factors still remained outside the realm of human manipulation: the climate and market. The gains derived from improved technologies were strongly constrained by these two. Simply said, vagaries of climate and market influence and swing agricultural production immensely.

However, contemporary agricultural practice has somewhat understood the roles of climate and market. Developed nations use natural sciences to predict the short- and long-term climate behaviour. They apply management science to predict and understand market in both shorter and longer terms. The guarantee of these predications is, of course, debatable. Nevertheless, achieving greater clarity in these enterprises has empowered developed nations to perform better, given that the other variables in the agricultural enterprise had already been brought under human control. Thus we humans have learnt to fit agriculture into human context. We are fully convinced that the science of agriculture and the business of agriculture need to go hand in hand to achieve better results in production and profitability. Developed nations focused on extensive cropping practice, whereas a majority of developing nations resorted to intensive cropping practice. Developed nations, because of their innate economic capability, attempted producing more and more by employing new science and novel technology (e.g. use of combines, mechanical sowers, harvesters). The developing nations, on the other hand, invariably, use the massive human-power base available to them at low cost and therefore use less-efficient, or sometimes even obsolete, technology. It was, in each of such starkly different contexts, a case of recognizing and then capitalizing on one's competitive advantage that has grown.

To recap what we have seen before, contemporary agricultural practice involves efficient incorporation of animal and plant sciences, agricultural economics, business management, and marketing. The notion of agriculture in developed nations is 'whole-farm business', subscribing to the dictum 'better to solve the whole problem in an approximate way rather than to solve part of a problem in a precise way'.

Management is an integral part of the agricultural enterprise today. It is a powerful tool to remain productive and profitable. Sound agricultural management depends on sound knowledge about farming processes. But fundamentally it requires a skill in juggling diverse components — the intricately intertwined biological, economic, and human components — of a whole farm. However, we need to remember that each component is unique, with its own special characteristics. The success of a farm business relies on the ability of the farmer in achieving his/her goals through efficiency in technical production and sound financial management, targeting profit. Problem-solving skill is another critical dimension of effective management, since different kinds of problems can easily arise in farming and surprise (occasionally 'shock' as well) the farmer. Such surprises and shocks are inevitable in farming, simply because so much of the farm system consists of living material: crop plants, cattle, sheep, and even pests, pathogens, and weeds. Their behaviour as living systems is unpredictable. At least until this point of time, we have no wherewithal to predict them. Each life form thrives in its own set of specific conditions aiming the best performance (e.g. growth, reproduction). But we need to recognize that the farm ecosystem is a fragile system and conditions will usually be suboptimal. Climate is yet another element of that which can spring surprises, since with all our modern technology (e.g. satellite imagery), we still cannot forecast the weather with 100% guarantee.

The gist of agricultural management will be to make the system work at its greatest efficiency with minimum inputs achieving maximum outputs. In contemporary agricultural contexts, outputs will be production and profit, whereas inputs will be a range of biological, economic, and human investments. An efficient farm manager will aim to put together all the inputs so that he/she will achieve as many of the desired, which will become the prescribed objectives within a determined time frame. A clever manager will also keep in view the fact that not all of one's objectives can be realized fully, and there will be inevitable trade-offs. But that clever manager will also remember that he/she will make every possible effort to minimize trade-offs, by judiciously assessing the risks involved and implementing appropriate remedial measures at appropriate times. A thorough manager will also make right judgements by analysing and assimilating the past information and experience, along with incorporating current research information. Right judgements have always enabled good decisions. A sound understanding of scientific principles always predisposes a manager to making more well-founded management decisions. Science is an intellectual procedure that seeks to explain the cause and effect relationships between two aggressive variables in the contextual ambience of several related, less-aggressive variables. Scientific thinking and ability enable the farmer to perceive the role of either an individual or multiple factors that influence a process. Scientific reasoning operates either by simplification and excluding the factors except those being investigated (reductionistic practice) or by looking at large parts of production systems and by measuring the performance of various parts collectively and cohesively (holistic practice) (Raman 2013a).

Recognition of the finiteness of materials (e.g. natural, human, and financial) is the force that drives Environmental Economics, which seeks to explain their distribution on the basis of how governments provide options of their management via support and subsidies. Is this a reasonable approach? Today, Environmental Economics is considered a scientific discipline, yet one innate strength (or weakness?) is that it traditionally considers social outcomes more aggressively than environmental outcomes. Humans are fundamentally driven by their emotions, and science tends not to get involved in asking questions about this. Environmental economists, in their effort to offer solutions to complex social problems, generally tend to simplify the complexities of the human world into variables that can be decoupled from the rest for measurement, losing the organic interconnectivity of a society's living processes.

The critical thing to recognize here is that the dynamics of farm practice involves the appropriate blend of science and economics, so that the most desired outcomes — productivity and profitability — are realizable. A purely scientific approach to deal with farm practice and agricultural problems, divorced from economic necessities and realities, will only provide a partial solution, and a purely economic approach that ignores scientific trials and practice will be just as flawed.

1.5 Precipitation of Crises

Thus far, I have drawn your attention to three closely knit, complex matrix of industrialized (conventional) agriculture: (i) adoption of efficient technology, (ii) clear economic goals, and (iii) clever management strategies. This matrix contributed in a major way to a rapid degradation of the Earth's limited land, for instance. The magnitude of the problem is clearly demonstrated in Australia. From the time of the arrival of the Europeans to 1975, 45% of agricultural land badly needed remediation, because of various forms of degradation inflicted to that land because of farming practices. For example, soil erosion increased dramatically with the introduction of European-farming practices in Australia during that time (Woods 1984). Extensive removal of native vegetation, to make room for farmlands, exposed the land, destabilized soil structure, and contributed to soil erosion by water and wind. Intensive cultivation practices have resulted in loss of organic matter on topsoil and damaged the soil structure resulting in reduced capacity for infiltration and surface waterlogging. Degradation of vegetation was another obvious result of European-farming practices. Natural plant-population clusters became scanty, losing their density and vigour. The proportion of native perennials, which mostly constituted the natural vegetation, declined in a substantial manner, resulting in vast tracts of vacant land, thus making it vulnerable to invasion by undesirable plant elements. A fabulous example comes from the distribution of the most-dreaded *Parthenium hysterophorus* (Asteraceae), which has spread across almost all of the vast tracts of erstwhile rich pastureland of Queensland (e.g. Mitchell Grass Downs and Brigalow Belt) (Fig. 1.2) (Dhileepan et al. 2018). One dramatic and far-reaching outcome of clearing of native trees for agriculture in Australia is dryland salinity (Fig. 1.3). Native vegetation included long-living (perennial) woody-tree species that transpired large volumes of water and maintained groundwater far below the soil surface. In the wake of modern agriculture, vast tracts of scrub and forest land have been cleared and replaced with short-lived herbaceous plants, which utilize less volumes of water. Eventually, groundwater moved upwards, bringing the deep-seated Na and K salts up to the surface (Cocks 1992). Soil acidity, due to land mismanagement — injudicious use of fertilizers such as super-phosphate and other synthetic fertilizers and absolute removal of crop residues from the land which has the capacity to neutralize the soil's acidic content — has risen (Cumming and Elliot 1991). Available soil nutrients have tapered to micro quantities. Uninterrupted cultivation drained them and that in turn induced decline in the quality of soil structure. To replenish nutrients, farmers started injecting synthetic fertilizers (Derrick and Dann 1997). Similar to the recent surge in the use of synthetic fertilizers to strengthen the weakening soil, we have been using violent and aggressive chemicals, such as dieldrin, heptachlor, and DDT, to keep pestiferous arthropods and pathogens under control. Although these applications did offer immediate benefits, we now realize that they have caused more harm to the soil. Residues persist in the soil and build up exponentially, which in turn have been damaging the soil biota and their fascinating diversity. Such issues arising out of badly thought of land-use patterns occur plentifully throughout the world.

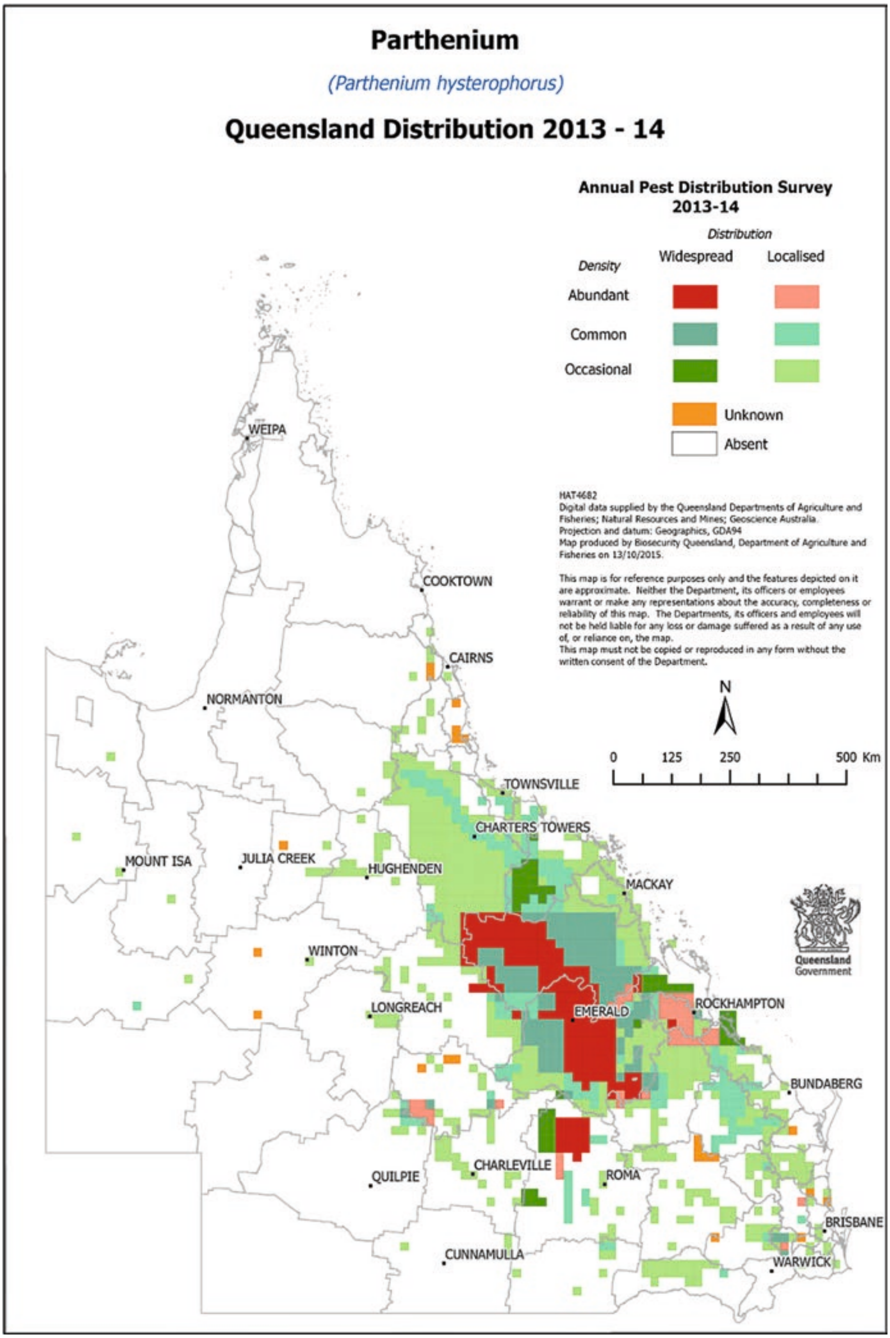


Fig. 1.2 Distribution of *Parthenium hysterophorus* in Queensland (Australia). (Source: https://www.daf.qld.gov.au/__data/assets/pdf_file/0003/790491/Parthenium_2013.pdf [Courtesy: K. Dhileepan, Queensland Department of Agriculture & Fisheries, Brisbane and the Queensland Department of Agriculture & Fisheries, Brisbane, Australia])

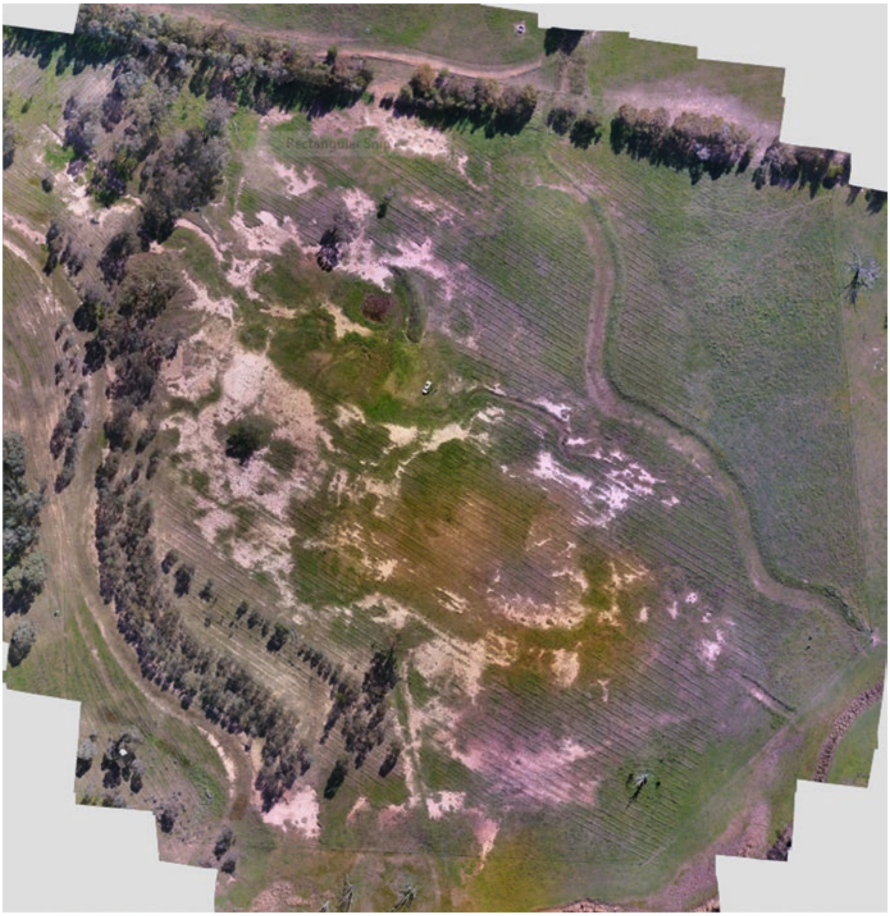


Fig. 1.3 Aerial imagery (drone photography) of a representative landsite (Sloanes Creek, Central-West New South Wales, 32°85′ S, 148°93° E, head-water catchment: *c*. 580 ha) showing prominent salinity-induced scalds. (Courtesy: David Mitchell, Department of Primary Industries, Government of New South Wales, Orange, NSW, Australia)

1.6 Sustainability

In many parts of the world, we have been inducing significant alterations to our natural environment, simply because economic criteria dominate over ecological criteria in our land-use decisions. The clarion call of Rachel Carson (1963) conscientized many of us of the extent of the critical and long-term damage such alterations could cause to our biophysical environment and, consequently, to our agricultural efforts. We began searching for a model that would enable us to achieve both economic and ecological goals — a sort of 'win–win' situation — so that the Earth can provision the materials for a longer period than our present economics-driven agricultural practices will allow.

At this point, we need to reflect on the question 'how did our ancestors manage their environment?' We need to know how pre-industrial civilizations coped with climate change, which certainly existed in those times as well (Pain 1994): (i) It was not so much climate change that caused problems, but the entrenched modes of adaptations to change. (ii) Such responsiveness depended on individual and collective choices, which were, of necessity, shaped by the past. (iii) The development and use of knowledge was the main mechanism for survival in conditions of rapid change. This means that adaptation to changing conditions depended on the perception and interpretation of the signs of impending change, on the timely development of knowledge, technology, and organization in reaction to those signs. (iv) By virtue of their privileged position, the elite who had a formal and social mandate to lead were often shut off from direct or even indirect experience of the signs of change. They had the power to maintain their lifestyles and the way things were when it was no longer prudent to do so. These perceptions enabled growing numbers of people to accept the concept of sustainability, a concept that could help us develop a set of guiding principles and goals to promote equity between and within generations of humans. Working for these outcomes will involve us in (i) maintaining the Earth's life-support systems and (ii) improving individual and community well-being.

In contrast to such a broad-based ecological perception of sustainability, economists would generally think of sustainability in narrower terms of maintaining consumption at a constant level forever. Unfortunately, economic thinkers seldom recognize that degradation of the biosphere will eventually dry up society's spending power. If we were really living in ways that would secure food consumption in the future, we would also be monitoring and regulating the use as well as abuse of our biophysical resources (Diesendorf 1997). Carson's *Silent Spring* received several follow-up commentaries in the 1960s (e.g. Boulding 1966; Mishan 1967), which stirred public, scientific, and political debates on achieving sustainability. The United Nations convened a conference on the Human Environment in Stockholm in 1972. Perhaps the most significant of the then prevailing thoughts was that of Meadows et al. consolidated in the publications *The Limits to Growth* (1972) and *Beyond the Limits* (1992). Meadows et al. illustrated the material and environmental limits to future growth in the way we use materials and energy. Their global model suggested that industrial capital would depreciate faster than any new investment could rebuild it. In brief, the global outlook was painted bleak and catastrophic. However, the Meadows et al. viewpoints have been received with considerable resentment from practitioners of economics.

In the 1980s, public consciousness of environmental issues, such as changes in global climate patterns, deforestation, and pollution, increased substantially. The newly formed green political parties gained representations in local, regional, and national governments. The United Nations set up the World Commission on Environment and Development in 1982 under the chairmanship of Gro Harlem Brundtland. The Brundtland Report, titled *Our Common Future* (1987), heralded in the concept of sustainable development, defining it as 'the development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. The weakness of this definition is that it does not explain either development or needs. The word 'needs' is confusing, since it relates quite generically to both ecological sustainability and economic wants. However, the body of the report does refer to issues such as equity between and within generations, conservation of biodiversity and ecosystems, dealing cautiously with risk and uncertainty, economic development and well-being, and community participation. This report emphasizes economic development, but suggesting a different meaning from economic growth. As a follow-up of the Stockholm Conference, the Earth Summit held in Rio de Janeiro in 1992 facilitated several international negotiations and decisions related to the environmental security of the Earth, its biophysical materials, and the people (Grubb et al. 1993; Turbayne 1993).

1.7 Sustainability and the Natural-step Framework

The stark reality is that agriculture is a commercial enterprise. How can a commercial enterprise design its activities for a sustainable future? The natural-step framework (Nattrass and Altomare 2001) offers a cohesive linkage between commercial enterprise management and environmental management by exploring a concept called corporate sustainability, building on the following: (i) The whole structure of industrial society is based on a faulty design. Ours is a take–make–waste society that violates the conditions for sustainable human life on the Earth. To understand the problem, we need to take a natural systems view of our society and its relationship to the environment. (ii) Although the elements of the problem are complex in their many dimensions, the core issues are easy to understand through the conceptual framework. (iii) It may not be too late for industrial society to take action, if we act now. There is no more time for business as usual. It is not necessary or important to assign blame. It is necessary to take action, to change our present unsustainable course. (iv) Humanity is now able to take its evolution into its own hands by conscious choice and design. Some innovative companies are already taking conscious evolutionary action, and some of those are using the natural-step framework in that process. The natural-step framework provides an elegant and simple design to integrate environmental issues into the frame of business reality and to move the enterprise towards sustainable development. It includes four core processes: (i) perceiving the nature of unsustainable direction of business and society and the self-interest implicit in shifting to a sustainable direction; (ii) understanding the first-order principles of sustainability, i.e. the four system conditions; (iii) strategic visioning through backcasting from a desired sustainable future; and (iv) identifying strategic steps to move the company from its current reality towards its desired vision.

1.8 The Challenge of Ecological Sustainability

We earlier saw that the term 'sustainable development' gained global acceptance after the recommendations made by the UN-sponsored World Commission on Environment and Development (UNCED) (The Brundtland Commission 1987).

From that time on ‘environmental sustainability’ and ‘sustainable development’ are being discussed in many quarters around the world.

The environmental sustainability concept originated essentially out of social concerns: seeking improvement in human welfare by protecting the raw materials used by humans and by ensuring that the sinks for human wastes do not overflow (Goodland 1995). Environmental sustainability is a social goal that will only be realized when humanity learns to live within the limitations of the biophysical environment, by purposefully maintaining the Earth’s natural-material capital both as biomass and as a sink for wastes. Achieving this will also preserve the economic subsystem of the Earth’s ecosystem. The critical factor will be to strike a judicious balance between production and consumption. Of course, any depletion of non-renewable resources is unsustainable in the strict sense of the term; however some conservationists argue that modest use of materials will be acceptable, provided their depletion rates are somewhat equal to the rate at which renewable substances can be created.

Sustainable agriculture incorporates three arms of sustainability: social, environmental, and economic. Any development activity should not only be socially acceptable and economically viable but also environmentally sensitive. The broad focus in the context of sustainable agricultural development will be the overall improvement of the well-being of humans by reducing poverty, hunger, and eventually disease, simultaneously maintaining the human-support system, the natural capital, which includes the environment’s sink (for the waste materials) and source (natural materials). Global human consciousness has now evolved into a widespread appreciation that our assets as a species include natural-material capital. The notion of environmental sustainability builds on this awareness and focuses our concern onto the present state of our soil, atmosphere, water, forests, and wetlands. Our ecosystems need, at the very least, to be conserved, or better still, conserved and given the security of a global commitment to their not being put at risk again, plus strategies and works on the ground to make this more than rhetoric.

1.9 Has Economics, as a Discipline, Responded Positively?

The answer perhaps is ‘not’, as wholesomely as the occasion would demand. Prevailing models of economic analysis treat consumption of natural capital as income, and such an approach promotes unsustainable patterns of economic activity. Consumption at the cost of natural capital is not income. Common sense prompts us to recognize that our means of producing income needs to be sustainable, but at the present rate of consumption, natural capital is becoming slimmer, scarcer, and scantier. Consumption of natural capital will lead to liquidation. Environmental sustainability needs thought, effort, and action that has a conservation focus. It is time that we accepted that natural capital is no longer a commodity to be used indiscriminately and injudiciously, but to be used with extreme prudence and care.

The view that environmental sustainability is critical only for (and in) developing countries is a myth. It is the developed countries — not only in per capita terms but also in absolute terms — that have precipitated so much of the Earth’s environmental