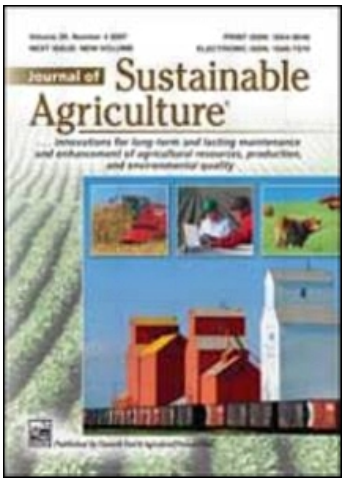

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The Plow and Agricultural Sustainability

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Settled agriculture began about 10 to 13 millennia ago in the valleys of the Nile, Tigris, Euphrates, and other rivers. Prehistoric tools developed included a short-handled forked branch that evolved into a hoe, and a long-armed hockey-shaped stick with a curved handle called an ard. The ard, which eventually evolved into a plow, won religious sanctions in many ancient cultures such as those of Greece, China, and India. The plow-based agriculture flourished in alluvial and loess-derived soils. These soils are generally coarse-textured, less cohesive, devoid of stones and suitable for growing closely spaced cereals such as wheat (Triticum aestivum). In contrast, hoe-based agriculture dominated in regions where widely spaced roots and tuberous crops, such as cassava (Manihoc esculenta) and yam (Dioscorea spp.), were grown on sloping lands. Mechanization of plowing with the tractor during the early part of 20th century vastly expanded the land area under cultivation. However, plowing also caused erosion and exacerbated environmental problems of non-point source pollution, emission of greenhouse gases (GHGs) and loss of biodiversity. The environmental movement, begun in 1950s and 1960s, led to the development of no-till (NT) farming. After approximately 50 years of its introduction, NT farming is practiced only on about 6% of the global cropland area, mostly in North and South America, and in Australia. Adoption of NT farming by resource-poor farmers of South Asia and sub-Saharan Africa is constrained by removal of crop residues for fodder and animal dung as residential fuel, lack of appropriate seed drill which can sow in an unplowed soil covered by crop residue mulch, and non-availability or prohibitively high cost of herbicides. While use of the

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plow is unsustainable on erodible soils, its use is essential until alternative sources of residential fuels are available to rural households, efficient seed drills are developed by village blacksmiths, and herbicides become economical and effective against perennial weeds or other viable options of weed control are available.

KEYWORDS history of agriculture, ard, soil degradation, evolution of no-till farming

INTRODUCTION

Human society traded an adventurous life of hunting and gathering for a bit of food security by changing to a settled agriculture. Farming or agriculture was probably begun 10 to 13 millennia ago, sometime during the Neolithic age, in the river valleys of the fertile crescent of the Near East, Asia, Central America, and the Far East. It is widely recognized among anthropologists and agricultural historians that inventors of plant-farming were women, and that those of livestock-raising were men. In a hunter-gatherer society, it is usually the men who hunt and the women who gather. Therefore, women had a better knowledge of plants (Hyams, 1952). It is probable that women started gathering wild fruits, seeds, and roots around their caves and shelters while men were hunting. Archaeologists have also suggested that in ancient China, women were the first to invent agriculture (Figure 1). The objective of this report is to describe the evolution of the plow as a tool that influenced agriculture. Rather than present a

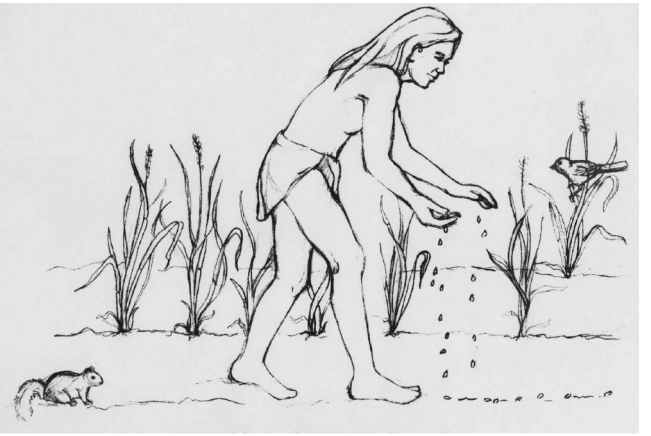

FIGURE 1 Agriculture was probably begun by women who started by scattering the seeds of cereals on a moist soil around homestead or caves about 10 to 13 millennia ago (Redrawn from Lal, 2004).

comprehensive literature review covering evolution of the plow in all regions of the world, which is beyond the scope of the present paper, this article provides a few examples to illustrate the importance of the plow and its modification with the increase in human population and increasing industrialization.

Agriculture being the foundation of human civilization, ancient cultures developed a reverence for soil (The Mother Earth). Several ancient cultures worshipped goddesses such as Ceres, Demeter, and Mary (Hyams, 1952). Scriptures of Indo-Aryans, emphasizing the importance of the goddess Laxmi, point to a belief in the eternal divine power of "Dherra" (Sanskrit equivalent of the Latin word Terra) or "Vasundherra" (The life-giving Earth). The Bhagwad Gita (500 to 900 B.C.) describes Vasundherra as the one whose "rivers are veins, the trees are hairs, the air the breath, and passing of ages the movement." Similar writings exist in ancient scriptures of most religions. The *Atharva Veda* states "What of thee I dig, let that quickly grow over; Let me not hit thy vitals or thy heart." These beliefs are also similar to those of the modern Gaia hypothesis proposed by Lovelock in the 1970s (Lovelock, 1979).

PREHISTORIC TILLAGE TOOLS

In the Mediterranean region, native cereals and legumes that grow naturally included Einkorn (*Triticum monoccum* L.), Emmer (*Triticum dioccum* Schrank) or wild wheat, barley (*Hordeum vulgare*) chickpea (*Cicer arietinum*), and flax (*Linum usitatissimum*). Prehistoric tillage, deliberate manipulation of soil to cover the seed and protect it from birds and rodents (Figure 1), may have occurred in the flood plains and deltas of rivers (e.g., the Nile, Tigris, Euphrates, and Indus). The alluvial soils of flood plains and deltas are light enough (less cohesive and free of stones and gravels) to be scratched by a forked branch or a digging stick (Figure 2). Prehistoric tillage tools were probably developed on easy-to-work and light-textured alluvial soils which are less cohesive and worked easily.

The digging stick may have been developed over several continents simultaneously. It is the digging stick or scratching tool that eventually evolved into a hoe, fork, spade, and plow (Wheelhouse, 1966). The human or animal powered implements supposedly evolved between 5000 and 3000 B. C. Prehistoric peoples used these simple tools to cover seeds so they were not eaten by rodents and birds (Figure 1). There was no settled agriculture until the digging stick was used to sow the seed (Figure 2), which was the dawn of settled agriculture.

With regards to the specific tools that evolved during the early stages, the world can be divided into two broad regions. The so-called "Hoe Belt," which included most of the present day U. S. along with Central and South

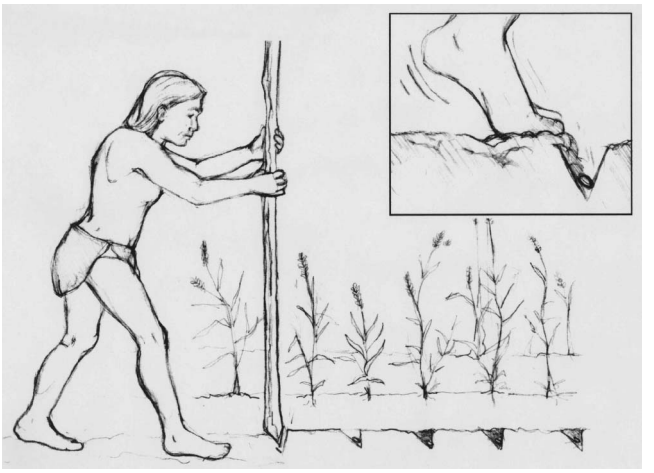

FIGURE 2 Prehistoric humans discovered that using a digging stick and covering the seed with soil (by foot) ensured better germination (Redrawn from Lal, 2004).

America, sub-Saharan Africa, the Indian sub-continent south of the Indo-Gangetic Plains, South east Asia, Australia and the Pacific. The soils, crops and landscapes of these regions, mostly in the tropics and sub-tropics, were suitable for the hoe-type of tillage tools because of the prevalence of stony soils, steep slope gradients, and predominately root crops and widely spaced coarse grains. The hoe is still used widely throughout sub-Saharan Africa (Figure 3), and poses a cultural challenge to modernization.

(a) **(b)**

FIGURE 3 The hoe or a short-handle digging spade (a) used by pre-historic farmers (Redrawn from Wheelhouse, 1966; Glob, 1951), and (b) widely used in sub-Saharan Africa and elsewhere where soils are stony, terrain is steep and widely spaced roots and tubers (cassava, yam, sweet potatoes, taro) are widely grown (Redrawn from Lal, 2004).

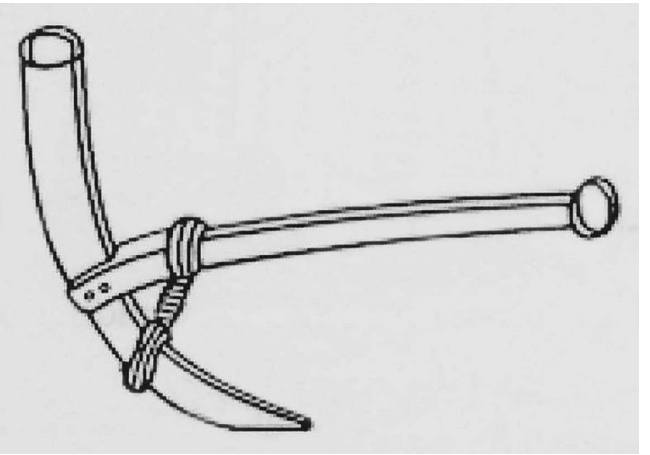

FIGURE 4 An ard was a paddle-shaped digging tool without a coulter or a moldboard. There were three principal parts: the beam, the handle and the head. The triangular head was initially made of wood, later of stone and more recently of iron (Redrawn from McKyes, 1985; Glob, 1951).

In contrast, the "Plow Belt" comprised of predominately alluvial soils in eco-regions of the Fertile Crescent of the valleys of the Nile, Tigris, and Euphrates. The soils, crops, and landscapes of the Mediterranean and temperate climates with mild winters, were suitable for growing closely spaced cereals and legumes. Fertility of alluvial soils of loamy texture was naturally renewed by annual floods (Hyams, 1952). These soils and climates were suitable for using a paddle-shaped spade or an ard (Figure 4), which was later adapted to be pulled by animals.

ARD

A gradual transition from a digging stick to an ard may have occurred over millennia. Instead of a simple digging stick, for sowing and collecting bulbs and tubers, humans started using a curved root or a forked branch to chip the ground and open a furrow. With experience, the prehistoric agriculturists may have cut one limb short and sharpened it to scratch the soil, another long to form a beam and yet another one to be used as a handle (Wheelhouse, 1966). Some prehistoric people in Southern Sweden, called the Hackers, supposedly used a rough hoe like plow made from fir. The transition between hoe and a plow was a Caschrom, a wooden spade shaped like a hockey stick with a pointed end and a curved handle. It may have been used in Egypt around 4000 B. C. (Wheelhouse, 1966).

A tillage implement called "ard" was probably developed in the Middle East, around 5000 to 3000 B. C. The term "ard" is derived from the old Norse word "ardr", and is related to the Latin word "Aratrum." It takes its name because of the fact that this implement works (arat) the soil. The "ard" or a primitive plow, is essentially a "hoe" with a long handle so that it can be pulled by humans or animals. It was a paddle-shaped digging tool without a coulter or a moldboard, and was basically a "scratch" or a digging tool to facilitate placing and covering the seed in the soil (Wheelhouse, 1966). There were three principal parts of an ard: the beam, the handle, and the head. The head, for scratching the surface of the soil, comprised the foreshare and the mainshare. The triangular head was initially made of wood and later of stone before being replaced by a metal share (White, 1967). In Borge, Norway, archaeological studies have shown that an ard was used in the area around 2000 B. C. (Wheelhouse, 1966). The plow drawn by animal traction has been used in Europe since 500 B. C. (Pidgeon, 1892; Fussell, 1952). Around 400 B. C., the Greek historian Xenophon recommended spring tillage by an ard because "the land is more friable then." Prophet Isaiah advised his followers to "convert swords into plowshares." During the 13th century, Spanish Moors described numerous practices of maintaining soil fertility in their book "Kitab-El-Filaha" (Olson and Eddy, 1943; Book on Agriculture). The ard was used in Mediterranean Europe until the 1950s and in southern Italy until the 1970s. The ard is still used in South Asia, Ethiopia, North Africa, and the Andes (Figure 5), and is the backbone of traditional farming.

There were two main types of ard. The DØstrup ard has an oblique share and head and can penetrate deep into the soil. It is named after the DØstrup bog/marsh in Jutland. The Triptolemos ard, has a pointed

FIGURE 5 An animal drawn ard is still used in South Asia, East Africa, and the Andean region of South America. (Redrawn from Lal, 2004).

share that produces a narrow v-shaped furrow and pushes the soil on both sides without inversion. It is named after the Greek God and hero "Triptolemos" (Lerche, 1994; Fowler, 2002). Agriculture in southwestern Asia in the region of Baluchistan (now in western Pakistan) dates back to 7000 B. C. (Wasson, 2006). There is evidence of stone-bunded agricultural fields cultivated to grow wheat and barley and to raise cattle (Kenoyer, 2003; Possehl, 1997). Pre-Vedic Harappan civilization in the Indus Valley dates back to 3200 B. C. (Wasson, 2006), when crops were sown in rows in a plowed field (Figure 6). The Harappan Civilization apparently collapsed ~ 1500 B. C. with the invasion of Aryans from the Caucuses and the Central Asian regions. Sanskrit scriptures, Vedas, provide some clues to such an invasion (Wasson, 2006). Vedas make reference to plowing and agriculture. The oldest, Rigveda (1000 B. C. in written form and the oral version for several centuries prior to that), refers to plowing (*Krishantah*) using large wooden plows (*Langgala or Sira*) drawn by 6, 8, 12, or even 24 oxen (Wasson, 2006). Iron tools appeared in the Gangetic plains around 1200 B. C. because soils were too hard for the wooden ard (Sharma, 1996). *Arthashastra*, authored by Kautilya/ Chanakya (Philosopher in the Court of Maurya Emperor Chandragupta, 340 to 293 BC), was written around 300 B. C. (Basham, 1971). The book explains the use of soils for livelihood and as a source of revenue for the

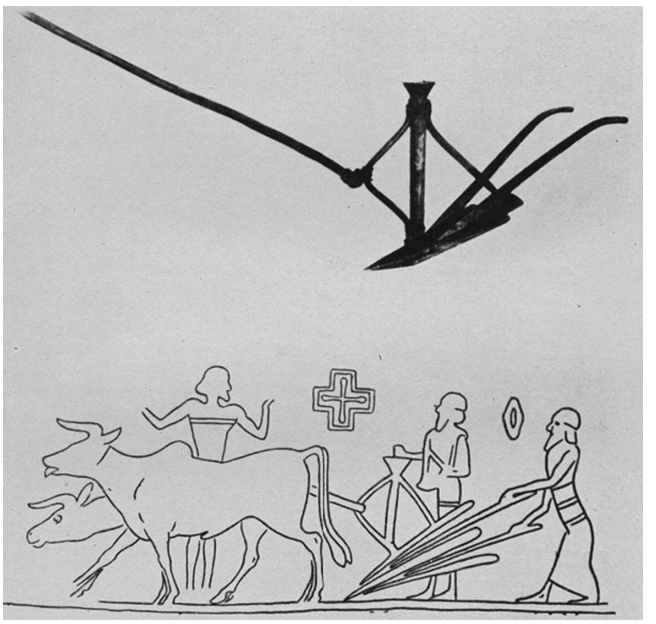

FIGURE 6 An animal pulled Babylonian seed drill used in the Middle East around 2100 B. C. (Redrawn from Fussell, 1952).

state economy. The book describes land use classification into categories such as that unsuitable for plowing (*bhumicchidra*) and thus to be used for pastures or forest. Simple concepts of soil fertility management are also described. Another book (*Krishi*) written around 300 B. C., classifies land into riverfed (*nadimtrika*) and rainfed or higher ground (*bagara bhumi*) and states that *nadimatrika* is more fertile and excellent for rice paddy cultivation. Both books describe the benefits of using cow manure as a soil amendment (Sadhale, 1999).

The plow won religious sanctions in many ancient civilizations (e.g., Indian, Chinese, Greek, Asyrian, and Egyptian). Similar to the Greek God Triptolemos, the Hindu Epic "Ramayana" (400 to 500 B. C.) is based on the divine birth of the Goddess "Sita" when pundits advised King Janak to till a field with an "ard" made of silver to break a serious drought. The ard share got stuck against an earthen pot buried in the soil, in which he discovered a baby girl named "Sita." Faithfuls believe that torrential rain fell as soon as the King lifted baby "Sita" in his arms. The epic Ramayana is still celebrated annually throughout South Asia and as far east as Bali in Indonesia.

The ard was later fitted with a seed funnel and used as a drill by Babylonians and Sumerians. Animal pulled seed drills were used in Egypt around 2100 B. C. (Figure 7), and soon thereafter in the Indus and Yangtze valleys (Yaalon, 1997; Hillel, 1998). Multi-tube seed drills were invented by the Chinese in the second century B.C. India and Japan had seed plows in pre-Christian times, but it did not appear on the European continent until the 17th century (Wheelhouse, 1966). The ard eventually evolved into a well known Roman plow, as described by Vergil around 1 AD.

FIGURE 7 A bullock drawn ard (Desi plow) was used in Indus Valley since 2000 B. C., a picture of field plowed along rive Indus around 2000 B. C. buried under a round dune (courtesy British Museum).

THE MOLDBOARD PLOW

The ard spread to Western Europe during the pre-Christian era (Fowler, 2002). However, the moldboard plow was not used in Western Europe until the 5th to 10th centuries AD (Fussell, 1952). In England, Jethro Tull (1674–1741) described different tillage implements, in the late 17th or early 18th century. He was an English agricultural pioneer before the industrial and agricultural revolutions. He was an early proponent of a scientific approach to agriculture, and invented a horse-drawn hoe for clearing weeds. He refined the primitive seed drill (initially developed by Sumerians around 1500 B.C.). The first European seed drill was invented by Camillo Torello and patented by the Vanetian Senate in 1566. Torello designed a seed drill that comprised of working parts set in motion when pulled by animals. This was the beginning of the mechanization of farm operations. He believed erroneously that an objective of plowing was to pulverize the soil grains into small particles so that they can be ingested by plant roots (Keen, 1931; Russell and Keen, 1941).

Several old plows are displayed at the U. S. National Museum of Plows (Lewton, 1943). The very first moldboard wooden plow in the U. S. was developed around 1740 (Table 1). In the U. S, the cast iron moldboard plow was designed by Thomas Jefferson in the 1780s, called "moldboard of least resistance." His plow consisted of a wooden part that lifts up and turns over the sod cut by the iron share and coulter. He presented his design to Charles Wilson Peale on 21 March 1815. The plow designed by Jefferson is on display at the Monticello Visitor's Center near Monticello (Martin and Stanton, 1988). It was patented by Charles Newbold in 1796 and marketed by John Deere in the 1830s (Table 1). It was the introduction of the moldboard plow (the Prairie Breaker) that literally conquered the west. Because it offered the least resistance as it was pulled through the soil, two horses or mules could easily operate it. The French Society of Agriculture awarded Jefferson its gold medal for the design. The use of steam power for traction in 1910 revolutionized agriculture, which eventually expanded the global cropland area from 250 Mha (620 million acres) in 1700 to 1500 Mha (3700 million acres) by 1980. This, along with other innovations, increased global food production at a rate faster than that of population growth and eventually ushered in the Green Revolution in the 1970s.

THE ENVIRONMENTAL DEGRADATION AND THE PLOW

Expansion of plow-based agriculture, however, brought mixed blessings. Plowing turned out to be the principal cause of accelerated soil erosion, non-point source pollution, hypoxia of coastal waters, and the widespread problem of land degradation and desertification. Even Vergil (1 AD)

TABLE 1 Some Historical Plows Exhibited at the U. S. National Museum (Adopted from Lewton, 1943)

# Year made	Description	Designer/Made For
1. 1740	A plow with a modern moldboard strapped with iron, a wrought-iron point and coulter	Pelatiah Kinsman at Ipswich, MA
2. 1783	A similar plow for lighter work	John Foster at Ipswich. MA
3. 1796	A plow designed by Thomas Jefferson and patented by Charles Newbold	Charles Newbold/John Deere
4. ~1800	A reproduction of the share and coulter plow used in Northumberland County, VA	Edwin Broun
5. 1800	A sod turning plow, cutter adjustable by an iron key	Mahlon Smith (Smith Model)
6. 1818	Gideon Davis Plow, an improvement over Charles Newbold cast iron plow	Gideon Davis, a farmer in Sandy Springs, MD
7. 1861	A Tavenner plow, with a cast-iron moldboard and a wrought-iron share and coulter	Manufactured in London Co., VA
8. 1848	A woodcock plow, the first reversible point ever made, patented by Bancroft Woodcock of Mouth Pleasant, PA	First used in Maryland
9. 1855/1860	A Carey plow, with wrought-iron point and wooden moldboard	Northumberland, VA
10. 1840	Eagle plow was with wheel, coulter and a draft rod	Ruggles, Nourse and Mason at Worcester, MA
11. 1893	Bull tongue plow, one-handle, iron shoe, similar to Spanish plow of the 16h century	Used in Mexico
12. 1893	Chinese plow, a wooden one-handle plow with yoke	–

doubted the value of plowing. He realized that the destruction caused by floods was due to plowing, and was the first to recommend contour plowing and installation of terraces on sloping lands. Erosion-induced soil degradation is believed by some to have led to the "collapse" of numerous ancient civilizations including the Phonecians, Mesopotamians, and the Harappan-Kalibangan and Mayan (Diamond, 2005). The Dust Bowl (the "dirty thirties") disaster in the 1930s in the U. S. was caused by drought whose effects were exacerbated by plowing. It was widely believed that "the Plow that Broke the Prairies" also caused the Dust Bowl. This man-made disaster was caused by deep plowing of the virgin topsoil of the Great Plains. The period from 1930 to 1936 was characterized by dust storms that blew eastwards and southwards in large dark clouds. The Dust Bowl affected 400,000 km^2 centered on the panhandles of Texas, Oklahoma, New Mexico, Colorado, and Kansas. In contrast to the teaching of Prophet Isaiah, "the plow share had done more damage than the sword."

TABLE 2 Famous Books that Created Awareness About the Adverse Impacts of Plowing and Other Agricultural Activities

Year	Book	Author
1939	The Grapes of Wrath	J. Steinbeck
1939	Soil Conservation	H. H. Bennett
1939	The Rape of Earth	G. V. Jacks
1942	Plowman's Folly	E. H. Faulkner
1946	The Furrow and Us	W. T. Jack
1953	The Conquest of Land Through 7000 Years	W. C. Lowdermilk
1962	Silent Spring	Rachel Carson
1968	The Population Bomb	Paul Ehrlich, Anne Ehrlich
1968	The Earth in Decay	G. L. Davies

The Dust Bowl was the turning point that initiated the environmental movement in the U.S. The environmental movement was led by the publication of a series of books written by Steinbeck (1939), Jacks (1939), Faulkner (1943), and others (Table 2). These books highlighted serious environmental issues, which were exacerbated by plowing and intensive agricultural practices.

The quest for knowledge about maintaining soil fertility began around the Christian era (Cato, 234–149 B. C.; Columella, 60 A. D.; Liebig, 1840; 1865; Olson, 1943; Edwards, 1943). Despite the widespread knowledge that plowing caused erosion, it was an important strategy for improving soil fertility especially when fertilizers were not available. In addition to preparing the desired tilth, plowing also enhanced soil fertility by accelerating mineralization of soil organic matter (SOM) and releasing nitrogen, phosphorous and other essential nutrients. It was eventually the advent of herbicides after World War II in the 1940s and the 1950s that provided an alternative to plowing for weed control. The invention of 2, 4-D after World War II; Atrazine, Simazine and Cynazine in the 1950s and the 1960s; Paraquat by ICI in the U. K. in the 1960s, and Roundup and Roundup-ready crops by Monsanto in the 1990s made no-till (NT) farming a practical reality. The NT farming involves seeding of crops in an unplowed field in which crop residues are maintained on the soil surface as mulch (Huggins and Reganold, 2008).

THE ERA OF NO-TILL FARMING

Sowing crops in an untilled field originated in the U. S. Corn Belt in response to the severe problem of soil erosion and non-point source pollution. No-tillage farming was practiced on about 100 Mha (250 million acres) of cropland worldwide in 2005 (Table 3). Most of the cropland area under NT farming is in the U. S., Brazil, Argentina, Canada, Australia, and Paraguay.

TABLE 3 Cropland Area Under no-till Farming in Different Countries (Adapted from Derpsch, 2007; Huggins and Reganold, 2008)

Country	Area under no-till farming in 2004–2005 (10^6 ha)
USA	25.3
Brazil	23.6
Argentina	18.3
Canada	12.5
Australia	9.0
Paraguay	1.7
Indo-Gangetic Plains	1.9
Bolivia	0.6
South Africa	0.4
Spain	0.3
Uruguay	0.3
New Zealand	0.2
France	0.2
Chile	0.1
Colombia	0.1
China	0.1
Others	1.0
Total	95.6

Resource-poor farmers in Africa and South Asia are still using the traditional ard or hoe developed 5 to 7 millennia ago. An emerging constraint to the spread of NT farming in the U. S. Corn Belt is the removal of corn stover as a feedstock for bioethanol production. This strategy amounts to "robbing Peter to pay Paul," and its long-term impact must be carefully assessed. Principal constraints to adoption of NT farming by resource-poor farmers are: (i) removal of crop residues for fodder and household fuel, (ii) non-availability of herbicides to control weeds, and (iii) increase in nutrient availability through mineralization of SOM accentuated by plowing. Despite its adverse effects on soil quality, plowing increases crop yields when fertilizers, herbicides and soil amendments are not used, as is the case for small land-holders of the tropics and sub-tropics.

Conversion from plow tillage to NT farming is essential to a sustainable use of soil resources. Similar to the turning point brought about by the catastrophic Dust Bowl in the U. S., a revolutionary breakthrough is needed in Africa and Asia to discard both ard and hoe which have ruled farmland for millennia. This revolution may have to be in the form of providing a clean cooking fuel to the rural communities of Asia and Africa. Finding a viable substitute to using animal dung and crop residues as cooking/heating fuel would enable their use as a soil amendment, which would pave the way for a widespread adoption of NT farming. Buffalo chips for fuel were used in the American Midwest Plains during the 18th and 19th centuries (Holmes,

2006). Indeed, animal dung is still used as a principal household fuel in South Asia and eastern Africa. Finding a clean household fuel, as a substitute for crop residues and dung, is essential to improving soil fertility and paving the way for adoption of NT farming (Lal et al., 2007). After 10,000 years of using plow, farmers are now realizing that less is more (Karasov, 2002).

LEGISLATION AND PLOW-BASED AGRICULTURE

Agriculture in the U. S. was supported by numerous legislations dating back to the 1860s (Table 4). Three important pieces of legislation that ushered in the expansion of agriculture in the U. S. included: (1) creation of the United States Department of Agriculture (USDA) in 1862; (2) the Morrill Act of 1862, which provided funding to support "Land Grant" colleges for technical assistance to farmers; and (3) the Homestead Act of 1862, which offered land to settlers (160 acres for $26 after a 5-year residence).

TABLE 4 Landmark Policies that Facilitated Agricultural Expansion in the U. S. (Adopted from Andrews, 2006)

Year	Act	Provisions
1862	U.S.D.A.	Created to provide technical assistance to farmer with plow as its logo/seal.
1862	Morrill Act	Provides grants to support state "land grant" colleges for technical assistance to farmers.
1862	Homestead Act	Offers land to settlers (160 acres for $26 after five-year residence or for $1.25/acre after 6 months)
1877	Desert Land Act	Allows land claims of 640 acres at $1.25/acre based on unfulfillable promise to irrigate within 3 years
1878	Timber and Stone Act	Allows purchase of forest public lands in 160 acre lots at $2.50/acre, eventually repealed in 1955.
1935	Soil Conservation Service	SCS created based on the previous Soil Erosion Service created in 1933
1936	Soil Conservation and Domestic Allotment Act	Offers price stabilization incentive for farmers in exchange of soil conservation measures

The Soil Conservation Service (SCS), now called Natural Resources Conservation Service (NRCS), was created during the Dust Bowl era in 1935 (Andrews, 2006).

The "environmental movement" started in the late 1940s and 1950s, and gained momentum in the 1970s. The driving force behind the environments movement included Aldo Leopold and Luis Bromefield. Initiation of the "Earth Day" on April 22, 1970, was an important landmark (Table 4). The creation of the U. S. Environment Protection Agency (USEPA) in 1970, Soil and Water Resource Conservation Act in 1977 and Farm Security Act of 1985 were important initiatives which enhanced public awareness about environmental concerns, and interest in ways to alleviate the causes of environmental problems.

There were also numerous international initiatives with strong implications for environmental improvements in the global arena. Important among these were: (1) the Earth Summit in 1992, which created "Agenda 21" with guidelines for sustainable development in the 21st century; (2) the Kyoto Protocol of 1997, which established binding targets for developed countries (Annex I) to reduce emissions of greenhouse gases, and its adoption in 2005 by the world community without U. S. participation; and (3) the 2006 State of the Union Message of President Bush, in which he stated that Americans are "addicted to oil" and emphasized the importance of biofuel (Table 5). In his State of the Union address on January 23, 2007, President Bush proposed reducing oil consumption by 20% by 2017 and replacing it by renewable energy. The U.S. Senate passed the Soil Protection Resolution (SR- 401) on 23rd June 2008.

THE PLOW AND AGRICULTURAL SUSTAINABILITY

Human society has gone full circle with regards to "soil tillage" from the dawn of settled agriculture 10 to 13 millennia ago to the beginning of the 21st century. Rudimentary agriculture probably began with women (Hyams, 1952), scattering seeds around homesteads or caves in an undisturbed soil. The ultimate NT farming is just that—broadcasting of seeds by an airplane (e.g., pregerminated rice seeds broadcasted in a flooded soil) in an untilled soil. However, technological innovations which make NT farming a viable alternative to plowing are drastically different. These innovations include use of crop residue mulch, applications of systemic and specific herbicides, development of special coulter and seed drills for sowing through a mulch in an unplowed field, and availability of herbicide-tolerant seed, etc.

Agricultural production increased drastically during the second half of the 20th century. Average grain yield of crops in the U. S. increased between 1900 and 2000 by a factor 6 for corn, 3 for wheat, 2.5 for soybean (*Glycine max*), 4.5 for rice (*Oryza sativa*), and 4.0 for peanut (*Arachis hypogea*). The

TABLE 5 Environmental Landmarks Impacting Plow-Based Agriculture (Adopted from Andrews, 2006)

Year	Act	
1949	Aldo Leopold's "A Sand Country Almanac"	Calls for "land ethic"
1954	Watershed Protection and Flood Prevention Act (Small Watershed Act)	Authorizes SCS to subsidize water resource projects in exchange for soil conservation measures
1970	Earth Day (April 22)	Supports environmental protection
1970	EPA	President creates EPA
1977	Soil and Water Resource Conservation Act	Authorizes nationwide inventories of soil & water resource protection needs
1985	Farm Security Act	Creates CRP, adds "sodbuster" and "swampbuster" provisions denying federal benefits to farmers who start new production on erodible soils or wetlands
1992	Earth Summit (Rio de Janeiro)	Creates Agenda 21 for achieving sustainable development in 21st century
1997	Kyoto Protocol	Sets binding targets for reducing emission of greenhouse gases
2005	Kyoto Protocol	Goes into effect without U. S. participation
2006	State of the Union Message	President Bush says that Americans are "addicted to oil" and creates 25-25 vision

number of people fed by one U. S. farmer increased exponentially from 12 in 1930 to about 100 in 1990. These achievements were made possible by using modern plows that could command large areas, growing input-responsive varieties, and making plant nutrients and water available at critical stages of crop growth. While supporters of Malthusian views predicted widespread famines and starvation, especially in densely populated developing countries, soil scientists and agronomists perfected agricultural techniques which ushered in the Green Revolution and saved hundreds of millions from starvation.

Over millennia, developments in agriculture and growth in human population have been inter-linked. The world population was merely 4 million when agriculture began about 12,000 years ago. It increased to 5 million over the next 5000 years. It reached 7 million by 4000 B. C., 50 million by 1000 B. C., 100 million by 500 B. C., and 170 million at the time when Christ was born. The world population was 0.3 billion (B) in 1 AD, 0.31 B in 1000, 0.40 B in 1250, 1.65 B in 1900, 2.52 B in 1950, 6.06 B in 2000, and 6.5 B in

2006 (World Population Curve, 2000). In 1000 years, from 1000 to 2000, human population increased by 20 times. Since the beginning of agriculture, the world population has doubled at least 10 times from 4 million in 10,000 B. C. to 6 billion by 20 A. D. This increase was made possible by gradual improvements in agriculture from 10,000 B. C. to 1950 A. D., and drastic improvements during the second half of the 20th century.

However, the human population will never double again, and is predicted to stabilize at about 10 B by the end of the 21st century, and Malthus will be proven wrong once again (Anonymous, 2005). It will not double again because of the food security provided by the advances in agriculture made possible through the evolution and modernization of plow and other inventions. At the time when the world population was 940 million, Thomas Malthus (1798) warned that "population, when unchecked increases in geometric ratio. Subsistence, increases in arithmetic ratio". Malthus could have never imagined that the world population could increase to 6 B by 2000, and stabilize at 10 B by 2100. Neither could he foresee that subsistence could also increase in geometric ratio through revolutionary advances in agriculture.

While the supporters of Malthusian concepts have been proven wrong during the last two centuries, there is no cause for complacency in efforts to keep improving agricultural technologies. The fact remains that even greater challenges lie ahead. The future increase in world population, from 6.5 B in 2006 to 10 B in 2100, will almost entirely occur in developing countries. These are the countries where the advances in agriculture have lagged behind, and natural resources are severely degraded and under great stress. The vicious cycle of exploitative/extractive farming practices-low crop yield-soil degradation-lower crop yield is not sustainable economically, ecologically or socially. The perpetual food deficit and lack of basic amenities have also caused political instability and social unrest. Thus, there is a strong need for adopting sustainable systems of managing soil resources. This need is more now than ever before especially in Sub-Saharan Africa and South Asia where most of the world's food-insecure and poor live. Sustainable agricultural practices involve use of crop residues, and other biosolids (dung) as soil amendments, adoption of integrated nutrient management techniques to create positive nutrient balance, conservation of soil and water resources, and elimination of plowing.

CONCLUSIONS

Simple "scratch" or "digging" tools that were developed around 5000 to 3000 B. C. evolved into complex moldboard plows pulled by heavy machinery during the later part of the 20th century. Such innovations facilitated expansion of agriculture and enhanced food production to meet the needs of world population which increased from 1.65 billion in 1900 to 6.75 billion by

2008. With the quest for increasing food production, however, came an increase in soil and environmental degradation. These problems were exacerbated by excessive plowing, including the emission of CO_2 into the atmosphere and susceptibility to accelerated erosion by water and wind. Thus began the so called "Environmental Movement" between the 1940s and 1960s. Development of herbicides also provided a viable alternative to plowing for weed control. No-till farming with crop residue mulch started in the U.S. Corn Belt and has been gaining momentum, but not so in sub-Saharan Africa and South Asia. Principal constraints to adopting NT farming in developing countries are the non-availability or limited access to herbicides and the proper seeding equipment. Since the onset of settled agriculture about 10 to 13 millennia ago, methods of seedbed preparation have gone full circle. Agriculture began with scattering of seeds in an untilled field, and is now trying to achieve the same through the modern techniques of NT farming.

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