The Plow and Agriculture

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Agriculture is the foundation of human civilization. Thus, ancient cultures developed a reverence for soil (The Mother Earth), and for the tools used to sow crops into it. For example, scriptures of Indo-Aryans state the belief in the eternal divine power of "Dherra" (Sanskrit equivalent of the Latin word Terra) or "Vasundherra" (The life-giving Earth). The Bhagwad Gita (500-900 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. Yet, these beliefs are also similar to those of the modern Gaia hypothesis proposed by James Lovelock in 1970s (Lovelock, 1979).

Agriculture supposedly started some 10 to 13 millenia ago, sometime during the Neolothic age. The historic tool, developed over several continents simultaneously, may have been the digging stick. The digging stick or scratching tool eventually evolved into a hoe, fork, spade and plow (Wheelhorse, 1966). The human or animal powered implements supposedly evolved between 5000 to 3000 B. C. The objective of these simple tools was to cover the seed so that it is not eaten by rodents and birds (Fig. 1). There was no agriculture in the real sense until the digging stick was used (Fig. 2). 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 America, sub-Saharan Africa, Southern Asia south of the Indo-Gangetic Plains, south-east Asia, Australia and the Pacific. Soils, crops and landscape of these regions, mostly in the tropics and sub-tropics, were suitable for the hoe-type of tillage tools because of the prevalence of: stoney soils, steep

slope gradients, and predominately root crops and the coarse grains grown at wide spacings. Hoe is still used widely throughout sub-Saharan Africa (Fig. 3)

In contrast, the "Plow Belt" comprised of eco-regions of the Fertile Crescent of the valleys of Nile, Tigris and Euphrates. Soils, crops and landscapes of the Mediterranean and temperate climates with mild winter, were suitable for growing closely spaced cereals and legumes. Fertility of predominately alluvial soils of loamy texture was naturally renewed by annual floods. These soils and climates were suitable for a paddle shaped spade or an ard (Fig. 4).

Ard

Instead of a simple digging stick, for 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 pre-historic 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 (Wheelhorse, 1966). Some pre-historic 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. (Wheelhorse, 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 (Wellhouse, 1966). There were three principal

parts of an ard: the beam, the handle, and the head. Head, the scratching tool, comprised of 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 there about 2000 B. C. (Wheelhorse, 1966). The plow drawn by animal traction has been used in Europe since 500 B. C. (Pidgeon, 1892; Fussell, 1952). Xenophon, around 400 B. C., recommended spring tillage by an ard because "the land is more friable then". During the 13th century, Spanish Moores 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 the Mediterranean Europe until 1950s, and in southern Italy until 1970s. Ard is still used in South Asia, Ethiopia, North Africa and the Andeas (Fig. 5).

There were 2 main types of ard. The Døstrup ard has an oblique share and head and can penetrate deep into a soil. It is named after the Døstrup bog/marsh in Jutland. The Triptolemos ard, has a pointed 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). Indeed, plow won religious sanctions in many ancient civilizations (e. g., Indian, Chinese, Greeks, Asyrians, and Egyptians). Similar to the Greek God, the Hindu Epic "Ramayana" is also based on the divine birth of the Godess "Sita" when the King Janak was advised by pundits to till a field with an "ard" made of silver to break the serious drought. The ard share got stuck against an earthen pot buried in the soil, in which was discovered the baby girl named "Sita". Faithfuls believe that torrential rain fell as soon as the King lifted the 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. Animal pulled seed drills were used in Egypt about 2100 B. C. (Fig. 6), and soon thereafter in the valleys of Indus and Yangtze (Yaalon, 1997; Hillel, 1998). India and Japan had seed plows in pre-Christian times, but did it not appear on the European continent until the 17th century (Wheelhorse, 1966). The ard eventually evolved into a well known Roman plow, as described by Vergil around 1 AD.

The Moldboard Plow

The ard spread to Western Europe during the pre-Christian era (Fowler, 2002). However, the moldboard plow was introduced into Western Europe during the 5th to 10th centuries AD (Fussell, 1981). In England, Jethro Tull (1674-1741) described different tillage implements, in the late seventeenth or early eighteenth century. He designed a seed drill that comprised of working parts set in motion where it was pulled by animals. This was the beginning of the mechanization of farm operations. He believed that an objective of plowing was to pulverize the soil grains into small particles so that they can be ingested by plant roots.

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 first designed by Thomas Jefferson in 1784. It was patented by Charles Newbold in 1796 and marketed by John Deere in 1830s (Table 1). It was the introduction of the moldboard plow (the Prairie Breaker) that literally conquered the west. The steam power of traction in 1910 use of 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 the Green Revolution in the 1970s.

The Environmental Degradation and 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) 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 led to "collapse" of numerous ancient civilizations including Phonecians, Mesopotamians, and the Harappan-Kalibangan and Mayan. The "Dust Bowl" 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". In contrast to the teaching of Prophet Isaiah, "the plow share had done more damage than the sword".

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

Quest for knowledge about maintaining soil fertility began around the Christian era (Cato, 234-148 B. C.; Columella, 60 A. D.; Liebig, 1840; 1865; Olson, 1843; Edwards, 1943). Despite the widespread knowledge that plowing caused the serious problem of erosion, it was an important strategy of 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 and releasing nitrogen, phosphorous and other essential nutrients. It was eventually the advent of plant growth regulators after the World War II in

1940s and 1950s that provided an alternative to plowing for weed control--the herbicides. Invention of 2, 4-D after World War II; Atrazine, Simazine and Cynazine in 1950s and 1960s; Paraquat by ICI in U. K. in 1960s, and Roundup and Roundup-ready crops by Monsanto in 1990s made no-till farming a practical reality. No-till farming involves seeding of crops in an unplowed field in which crop residues are maintained on the soil surface as mulch.

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-till farming was practiced on about 100 Mha (250 million acres) of cropland worldwide in 2006. Most of the cropland area under no-till farming is in the U. S., Brazil, Argentina, Canada, Australia and Paraguay. The resource-poor farmers of Africa and South Asia are still using the traditional ard or hoe developed 5 to 7 millenia ago. An emerging constraint to the spread of no-till 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 longterm impact must be carefully assessed. Principal constraints to adoption of no-till farming by the resource-poor farmer 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 soil organic matter 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 of plow tillage to no-till 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 the ard and hoe that

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 soil amendment, which would pave the way for a widespread adoption of no-till farming. Buffalo chips for fuel were used in America's Midwest Plains during 18th and 19th centuries (Holmes, 2006). Indeed, animal dung is still used as 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 no-till farming.

Legislation and Plow-Based Agriculture

Agriculture in the U. S. was supported by numerous legislations dating back to 1860s (Table 3). Three important legislations 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 that provided land grant 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 5-year residence). The Soil Conservation Service (SCS), now called Natural Resources Conservation Service (NRCS), was created during the Dust Bowl era in 1935 (Andrews, 2006).

The "environment movement" started in late 1940s and 1950s, and gained momentum in the 1970s. the driving forces behind the environment movement included Aldo Leopolds and Luis Bromefield. Initiation of the "Earth Day" on 22nd April (1970) was an important landmark (Table 3). Creation of Environment Protection Agency in 1970, Soil and Water Resource Conservation Act in 1977 and Farm Security Act of 1985 were important initiatives to create public awareness about environmental concerns, and alleviate the causes.

There were also numerous international initiatives with strong implications to the 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 the U. S. participation, and (3) the 2006 State of the Union Message of President Bush in which he stated that the Americans are "addicted to oil", and emphasized the importance of biofuel (Table 4).

Future of Plow and the Global Issues

The human society has gone a full circle with regards to "soil tillage" from the dawn of settled agriculture 10 to 13 millenia ago to the beginning of the 21st century. The rudimentary agriculture began with scattering of seeds around homesteads/caves in an undisturbed soil. The ultimate no-till farming is just that -- broadcasting of seeds by an aeroplane (e. g., pre-germinated rice seeds broadcasted in a flooded soil) in an untilled soil. However, technological innovations which make no-till 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.

Conclusions

Simple "scratch" or "digging" tools 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 6.06 billion by 2000.

With quest for increasing food production, however, came 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 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. No-till is practiced on about 100 million hectare of cropland world wide, but mostly in North and South Americas. Principal constraints to adopting no-till farming in developing countries are the non-availability or limited access to herbicides and no-till seeding equipment. Since the on-set of settled agriculture about 10 to 13 millenia ago, methods of seedbed preparation have gone a full circle. The agriculture began with scattering of seeds in an untilled field, and is now trying to achieve the same through the modern techniques of no-till farming.

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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	?

Table 2 Famous books that created awareness about 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	Vanishing Lands	G. V. Jacks and R. O. Whyte
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

Table 3 Historical land maks 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 land grant 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

Table 4 Environmental land marks impacting plow-based agriculture (Adopted from Andrews, 2006).

Year	Act	
1949	Aldo Leopolds "A Sand Country Almanac"	Calls for "land ethics"
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

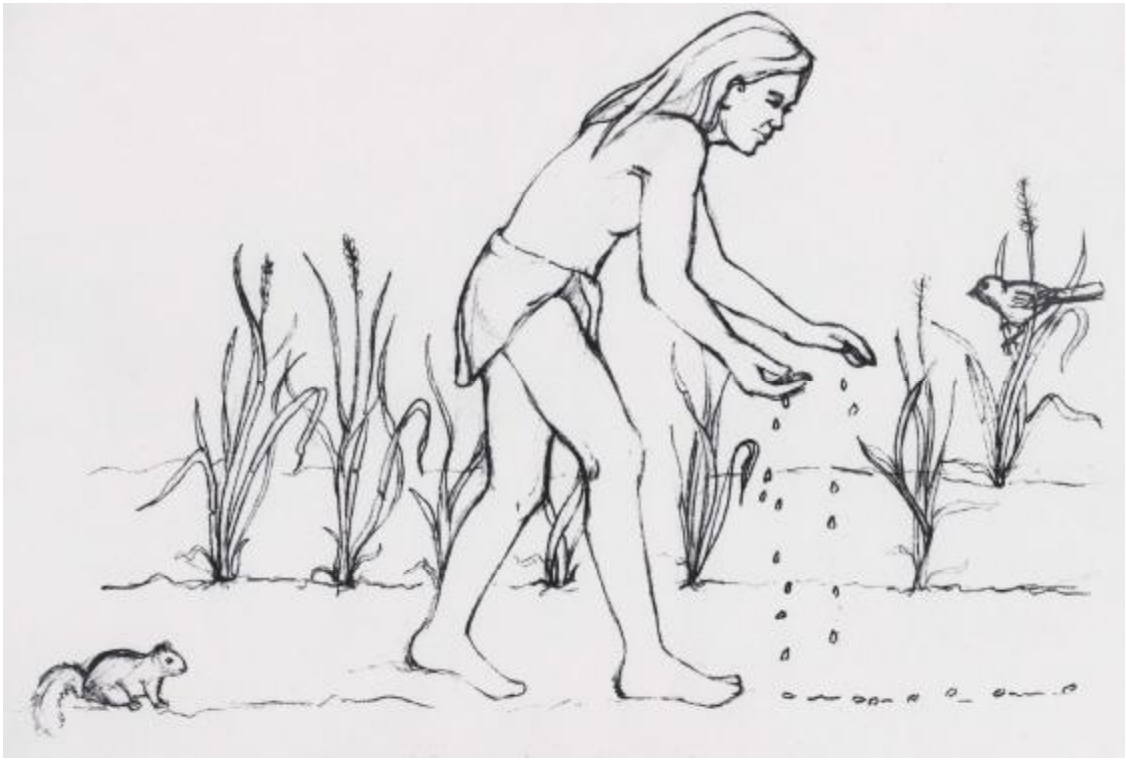

Fig. 1 Agriculture was probably begun by women who started by scattering the seeds of cereals on a moist soil around homestead or caves about 10 to 13 millenia ago.

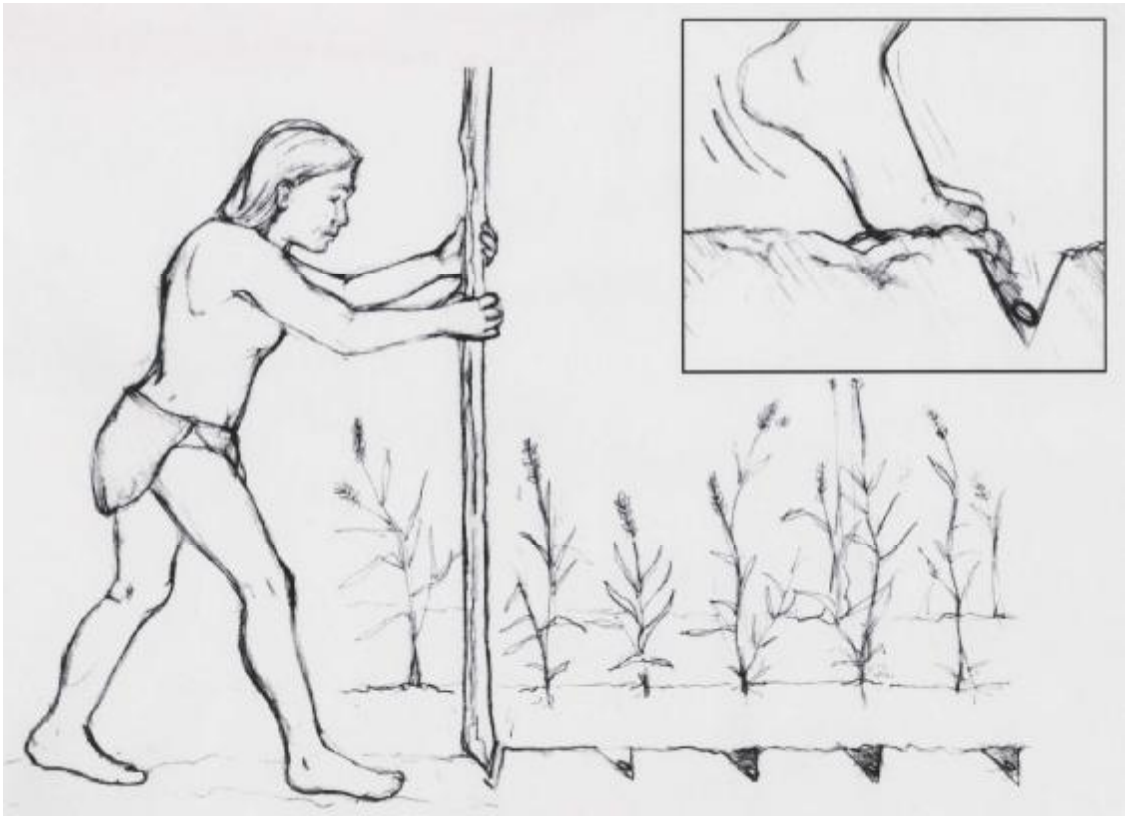

Fig. 2 The pre-historic humans discovered that the covering using a digging stick and covering the seed with soil (by foot) ensured better germination.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

(a)

(b)

Fig. 3 The hoe or a short-handle digging spade (a) used by pre-historic farmers, and (b) widely used in sub-Saharan Africa and elsewhere where soils are stoney, terrain is steep and widely spaced roots and tubers (cassava, yarn, sweet potatoes, taro) are widely grown.

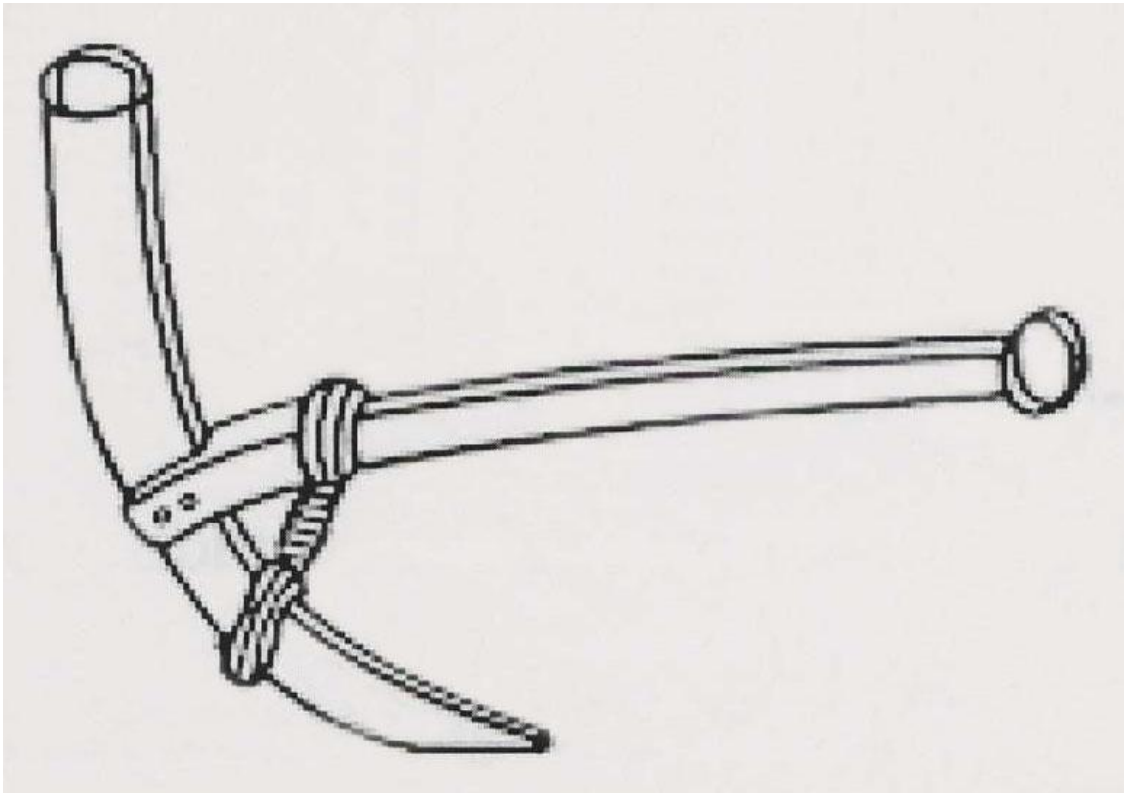

Fig. 4 An ard was a paddle-shaped digging tool without a coulter or a moldboard. There were three principal parts: the beam, the handle and the head. The triangular head was initially made of wood, later of stone and more recently of iron (Redrawn from McKyes, 1985).

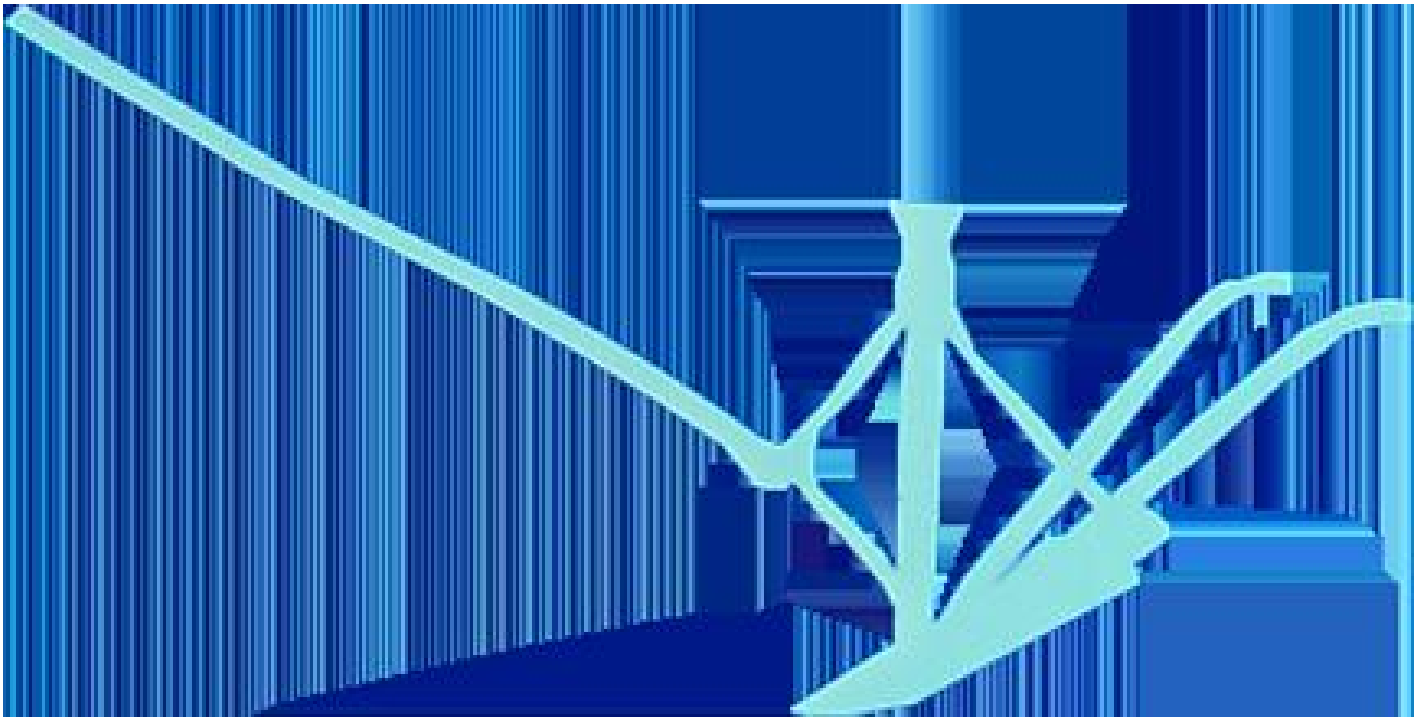

Fig. 5 An animal pulled Babylonian seed drill used in the Middle East around 2100 B. C. (Redrawn from Fussell, 1952).

(a)

(b)

Fig. 6 A bullock drawn ard (Desi plow) being used in Indus Valley since 2000 B. C., (b) a picture of field plowed along rive Indus around 2000 B. C. buried under a round dune (courtesy British Museum)