Agricultural mechanization - its role in the development of civilization

by L. Bodria - ITALY and K.T. Renius - GERMANY

Part 1 - Agricultural mechanization: a success story of mankind

by L. Bodria

1. Road to mechanization

1.1 Agricultural tools: driving force of human civilization

It is common knowledge that the first spark that ignited the long process of human evolution went off around 12,000 years ago with the transition of early humans from hunter-gatherers to agricultural societies.

The discovery of how to cultivate the land and to breed animals has transformed the earlier groups of hunter-gatherers into sedentary societies based on small villages. The food surplus allowed humans to establish food stocks, reduce mortality, raise more children concurrently, whereas this was not possible previously, and support a denser population, which in turn encouraged the development of larger sedentary communities.

The result is that world population significantly increased by about one million in 10,000 BC to an estimated value of 200 million at the Roman time, as the result of what historians call the "Neolithic Revolution", that is a virtuous circle of progressive increase of food supplies and a consequent population growth **(Fig. 1)**.

Considering that survival and well-being were strictly connected to agriculture, the first pioneering efforts of the human mind have been totally dedicated to the creation of tools and implements such hoes, sickle etc. able to facilitate the farming operations that therefore can be considered as the forerunners of modern agricultural implements.

We can therefore assert that agricultural engineering – in its earliest and simplest forms – was the first technological innovation that has radically changed the life and the structure of the human community and it may be properly considered to be the mother of all subsequent innovations that have led to the technological level in today's society **(Table 1)**.

Agricultural production and related technologies remained substantially unchanged for many thousands of years with a slow but steady increase in population and we must wait until the Middle Ages in order to attend to a new, important evolutionary leap.

Between the XI and XIV century Europe saw significant improvements in the agricultural techniques and technologies.

In this period of time a considerable development of handcraft and iron working led to the dissemination of several technological innovations. The production of agricultural hand tools grew greatly and the plough was significantly improved developing from the ancient symmetrical wooden plough into the mouldboard plough capable of turning over the heavy, wet soils of northern Europe.

The use of animal traction was significantly improved by the development on yoking of animals from the ancient strap system to front yoke for oxen and to horses collar which allowed the animals to download the weight of the whole body, greatly increasing the efficiency of coupling. To protect the hooves of horses at work also the practice of shoeing began to spread.

Among the major innovations of that period must be taken into consideration also the spread of watermills and windmills, initially developed in Roman times, which in Middle Age were greatly improved and disseminated for grinding grain and wood cutting allowing increasing by 40 times the productivity of human labor.

In this same time period, monasteries spread through Europe and became important centers for the collection and the diffusion of knowledge related to agriculture and forestry while large landowners introduced a better control of both their land and their laborers through the manorial system.

So farming technique developed as well, the concept of summer irrigation was introduced and there was a significant expansion of arable land through land reclamation and remediation. European farmers moved from two field crop rotation to a three field crop rotation in which one field of three was left fallow every year and new crop were planted.

Thanks to the combined effect of all these factors the efficiency of seeding (wheat) doubled from 1: 2 to 1: 4 and there was a significant increase in the quantity and quality of agricultural production, which in turn led to the development of commerce and an increase in population making a further step forward in the path of evolution of human society.

1.2 Agricultural Revolution

In 1700 the advent of the Enlightenment produced a sea change in human thought which led to the birth of modern science; reason and experience became the driving forces in the process of advancement of knowledge laying the foundation of modern scientific thought.

Even for agriculture began a period of radical change, the first texts of agronomy appeared and a series of innovations, improvements and techniques in Great Britain, the Netherland, and others neighboring countries gave rise to the so called Agricultural Revolution that represents the major turning point in farming systems.

Under the pressure of two important social factors:

- growing population but mostly the increase in number of urban dwellers creating an increase in demand for food;
- better organization of land management replacing the open field system with compact farms through the Enclosure Acts.

the agriculture saw a radical transformation process moving beyond the use of primitive techniques of subsistence to generate the kind of surpluses needed to feed thousands of people working in factories instead of in agriculture

Many factors have contributed to this deep change:

- introduction of four-field crop rotation with fodder crops, particularly turnips and clover, which greatly increased crop and livestock yields by improving soil fertility and reducing fallow;
- selective breeding;
- use of fertilizers with dung pits to hold and preserve animal manure;
- use of deep trenches for land drainage;
- New crops from trade with Americas, including corn and potatoes.

But absolutely crucial was the contribution of agricultural engineering that with the great improvement of existing tools and the invention of the first farm machinery began the long process of development toward the agricultural mechanization in modern sense.

A major contribution to provide the basis for modern mechanization comes from the English agricultural pioneer Jethro Thull. After some early attempts by Giuseppe Locatelli and Giovanni Cavallina in Italy, in 1701 he perfected a horse-drawn seed drill able to sow seed in uniform rows and cover up the seed in the rows **(Fig. 2)**. Later he also developed a horse-drawn hoe and Thull's methods were adopted by many great landowners.

In 1730 in Rotherham, England, the plough design was steadily improved with new shapes and covering the mouldboard with iron. The Rotherham plough was much lighter than conventional design and it began to be manufactured industrially. At the same time spread the use of horses for traction in substitution of oxen with an increase of 50% in the working speed.

Nel 1753 in Florence the"Accademie dei Georgofili" was founded, books of agronomy began to spread, and agricolture became a science.

Renewed agricultural practices and technical innovations produced an important increase in yield per land unit (seed efficiency raised to 1:7) and in food supplies that enabled an unprecedented population growth, freeing up a significant percentage of the workforce, and thereby Agricultural Revolution can be considered one of the catalyst of the following Industrial Evolution.

2 - The role of mechanization to feed the world

1.3.1 Mechanization after the Industrial Revolution

The extraordinary development of the last three centuries is well known: the Industrial Revolution of the 1800s and the Green Revolution of the second half of the last century has completely transformed society and the agricultural production system.

The world's population that until the 18th century had grown very slowly up to approximately 600 million, thanks to the growing availability of food resources and the improvement of economic conditions, begins to grow more and faster to get to nearly 7 billion today.

The transition from subsistence to market-oriented agriculture, which started three centuries earlier in industrialized countries, comes to complete fulfilment and today only 1-2% of the population produces enough food for the entire community. The remaining question of famine is not that we need more food, but how we distribute it within the world **(Fig. 3)**.

This unprecedented growth of the agricultural productivity at a global scale has been enabled by the joint action, by one hand, of scientific discoveries in the field of agronomy which led to the introduction of newer higher- yield seeds and to the expanded use of fertilizers and pesticides, and, on the other hand, by development of agricultural engineering technology that has made available machines and equipment more and more powerful and efficient.

In Europe theoretical studies on the improvement of the plough continued and the prototype designed by Cosimo Ridolfi, a member of Accademia dei Georgofili, and Raffaello Lambruschini, was awarded at the International Exhibition in Paris in 1855. A few years earlier, in 1835, an American blacksmith John Deere introduced the first steel plough and Cyrus McCormick invented the horse-drawn mechanical reaper [1].

At the beginning of the 20th century, the mechanical power finally comes into agriculture and starts the season of modern mechanization. In the US, Henry Ford introduced the first widely popular mass-produced tractor in 1917 and soon after the first tractors powered by diesel engine were born in Germany (Benz Sendling DS-6, in 1922) and in Italy (Cassani, in 1927).

Thus the tremendous transformation of the agricultural system of the 20th century began. Until the end of 19th century agriculture was labour-intensive, and it took place on a large number of small farms occupying more than half the population and a huge number of working animals. Nowadays agriculture is concentrated on a small number of highly productive and mechanized farms employing a thin share of active population and freeing major human resources for economic growth and development.

During its long pathway agriculture has increased by 25 times the land output that has grown from a seeding efficiency of 1:2 in primitive agriculture to 1:50 but the use of the machine was boosted 100 times the productivity of human labour by reducing the manpower needs from 1000 to 10 man-hours/ ha.

The 2014 Combine Harvesting World Record of an average throughput of 99.7 t/h over an eight hours period with a fuel consumption of 1.12 litres per ton and an average yield of 9.95 t/ha give full evidence of both the extremely high agricultural production values and the tremendous level of efficiency achieved by the modern mechanization. **(Fig. 4)**

1.3.2 Challenges for the mechanization of the next millennium

Agricultural machinery production is today a very efficient system in which both an intense and highly qualified research activity and a large and dynamic industrial sector in all the industrialized counties contribute with synergic effects.

In recent decades a crucial contribution to the exponential growth of the disciplines related to agricultural engineering comes from a broad international network of scientific societies and academies that have actively coordinated and promoted research activity in the field driving it towards highly innovative issues.

The International Commission of Agricultural and Biosystems Engineering (CIGR) worldwide, the European Society of Agricultural Engineers (EurAgEng) in Europe, and the American Society of Agricultural and Biological Engineers (ASABE) in the United States are very active in stimulating the development of science and technology in the field of Agricultural Engineering through Conferences, Publications, Networking and International lobbying.

In Italy, the “Accademia dei Georgofili” after 261 years still plays with unchanged prestige and authoritativeness an important role of guidance of development strategies for the agriculture with great attention to mechanization [2] [3]

The Club of Bologna, founded in 1989 by FederUnacoma as a free association of leading personalities on mechanization from research, manufacturers, and international Organizations, meets once a year in order to discuss the development of the agricultural mechanization worldwide. During the meetings the emerging issues and development needs for mechanization are discussed in order to prepare recommendations to be submitted to the policy makers for future actions **(Fig. 5)**.

Following this uninterrupted process of growth and modernization, mechanization has reached the goal of maximizing productivity and it is now preparing to face the challenge of the third millennium: sustainability.

The tremendous development of Information Technology is gradually turning machine from tools for increasing the “power” of human action to "smart" devices more and more autonomous and able to fit automatically local conditions.

Three are the mainstays of new smart mechanization:

- Global Positioning System (GPS), a satellite constellation system able to provide positioning data on the field with an accuracy from 20 to 2 centimeters;
- electronic sensors and automation allowing automatic control systems for operating machinery and implements;

- computer science for information processing;

that all together have led to the development of so called Precision Agriculture (PA).

Precision Agriculture is a farming management concept based on optimization of machine operations according to the local needs and the characteristics of the crops The capacity to locate the precise position in a field allows the creation of maps of the spatial variability of crops so that further operation can be locally optimized.

Crop yield monitors and different type of vehicle mountable sensors can provide precise information on the crops status (chlorophyll, moisture, diseases, weeds etc.) in order to optimize distribution of inputs.

The possibility to tailor chemical and fertilizer application using prescription maps together with advanced systems of automatic machine guidance and operative control is a major step towards sustainability of agricultural production in industrialized countries. Computerized management systems allow operations and inputs in order to achieve the traceability of production at the farm gate,

In parallel in less industrialized countries the paradigm of feeding the world should be declined promoting the development of appropriate forms of mechanization, thus enabling those countries to advance towards food self-sufficiency and economic growth.

Therefore, the aim of meeting the growing food needs of the future years may be prosecuted only if the development of the necessary technical means will be considered a strategic priority issue.

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Figure 1 - The population growth is closely correlated with the increase of the agricultural yield

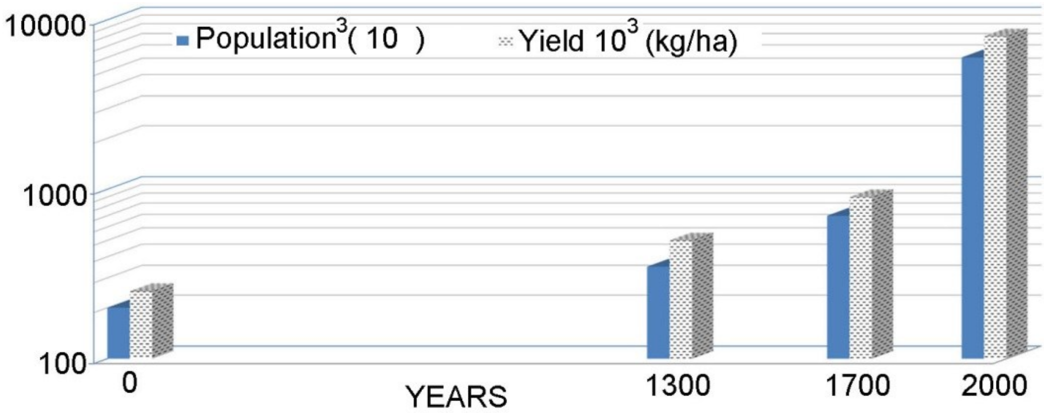


Figure 2 - The first agricultural machinery is the horse-drawn seed drill designed by Jethro Tull in 1701

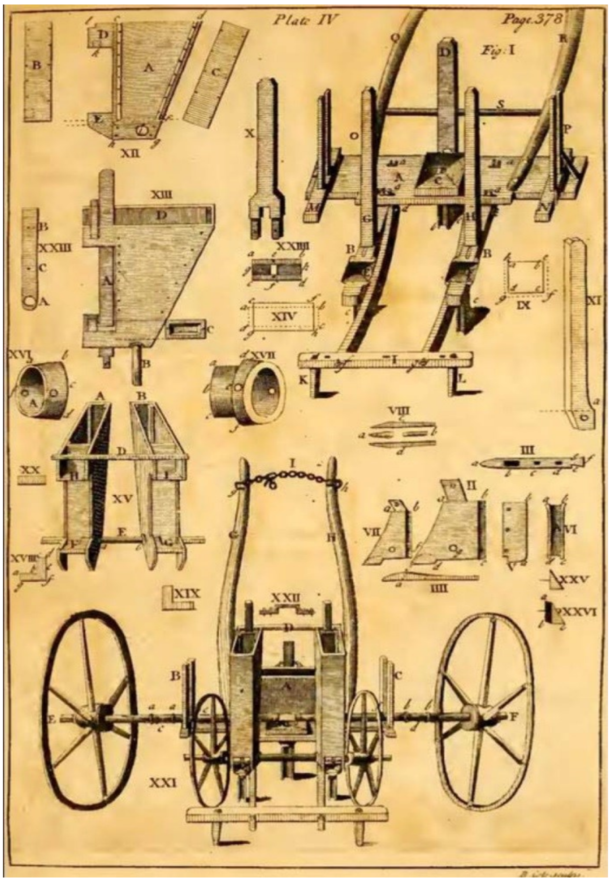


Figure 3 – Global average yields of major cereals, 1961-2009 [4]

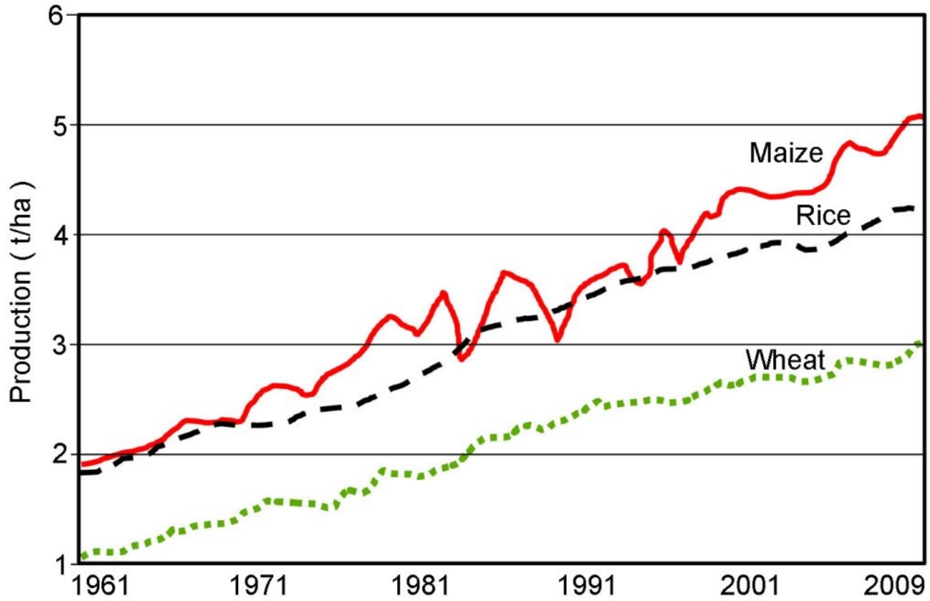


Figure 4 – In fifty years the fuel consumption per ton of wheat harvested is reduced to one third

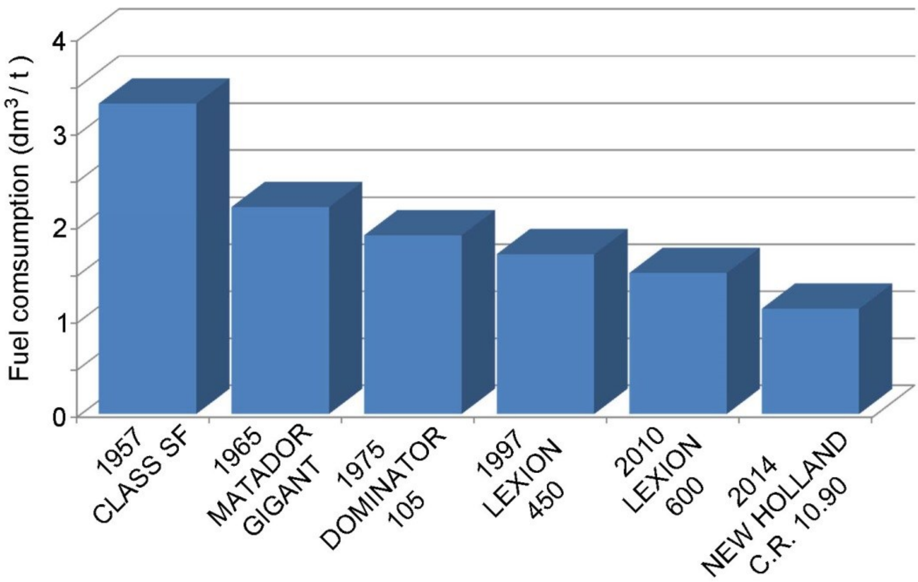
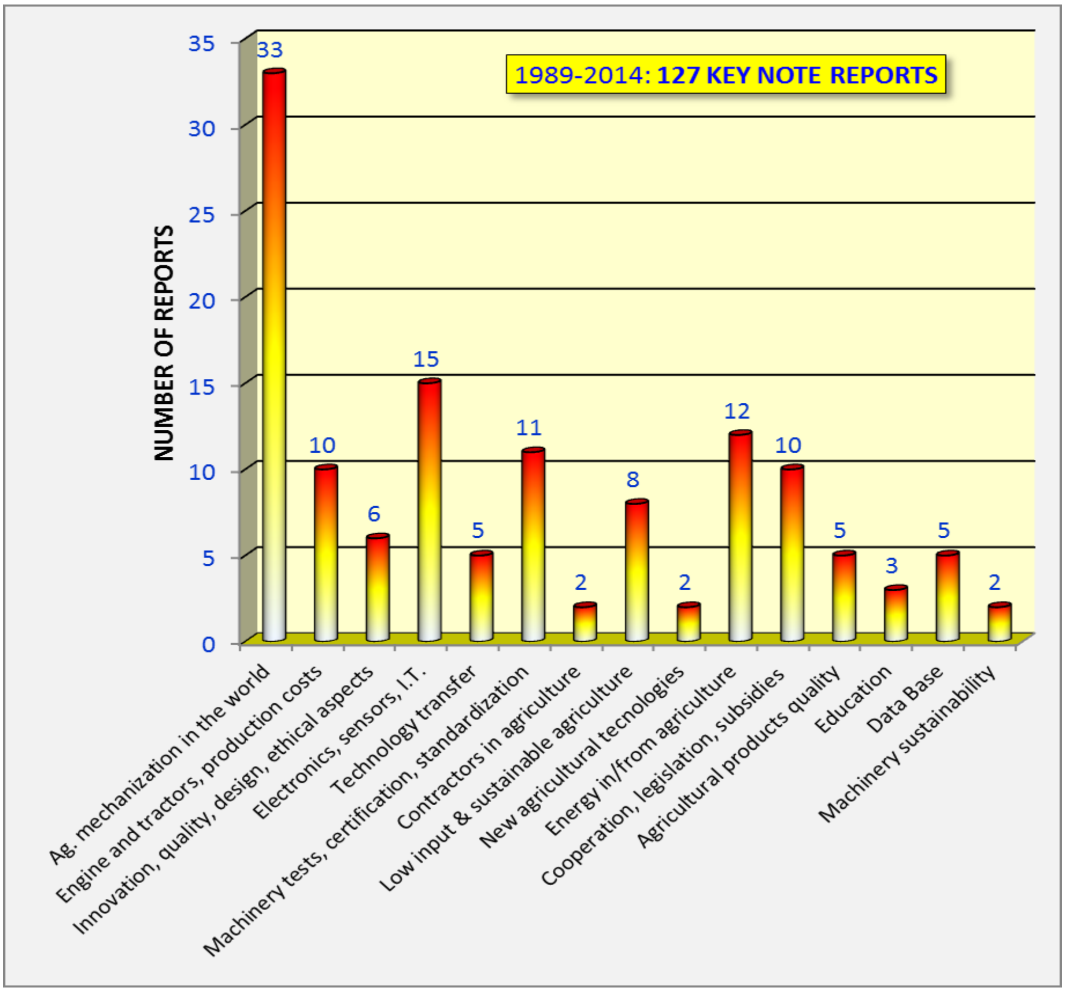


Figure 5 – The Club of Bologna has discussed in depth all the main topics of interest for the development of mechanization



Part 2 - Agricultural mechanization: a key for future mankind welfare

by K.T. Renius

1. Agricultural mechanization: a key condition for future mankind welfare

1.1 Enlarged responsibilities

Besides the well known function of feeding the world in the future there are additional aspects of agricultural mechanization. In total its mission can be structured into the following *three important roles* [1]:

- the *classical role*: mechanisation of plant and animal production, storage and process-sing in order to feed the continuously growing population;
- the recently added *environmental role*: mechanisation of raw material & energy production and landscape maintenance in order to safeguard the planet;
- the *strategic role*: mechanization to increase labour productivity in agriculture in order to develop welfare of complete national economies.

1.1.1 The classical role

Decades of global agricultural over production seem to be terminated – rather followed by future shortages in food supply. Agricultural mechanization supports two basic productivity factors of agriculture: *land productivity* and *labour productivity.*

Influence on *land productivity* is not dominating, however one of several important factors:

- Breading
- Fertilizing
- Irrigation
- Plant protection
- Post harvesting methods
- Mechanization

Mechanization benefits are – for example – improved yields, higher quality levels, reduced input materials, reduced human work loads and reduced losses. Old methods of harvesting cereals (as still used in many developing countries) have often losses of 20 or even 30% (FAO) why the losses of a modern combine figure only about 1% under usual conditions.

Influence on *labour productivity* is considerably higher – mechanization is even the by far dominating factor, **table 1**. This has resulted in low world market prices for basic agricultural products as compared to the prices of many other goods. In highly developed countries, people spend today only about 12% of their income for buying food (if beverages excluded). Regarding the future, a progressive increase of meat demand is expected resulting in a progressively needed increase of plant production relative to the population growth.

1.1.2 The recently added environmental role

Factors affecting a production increase of energy and raw materials are more or less similar to those mentioned above for food – with some exceptions or adjustments.

The problem is that the production of these goods reduces the available production area for food again – in addition to the progressive needed area for feeding animals.

These trends have led to many forecasts that the total plant production increase must be considerably higher than the population growth. Population growth is – for example – expected by FAO to achieve 9,1 billion in 2050. This is about 30% more than 2013. Several experts estimate however a total demanded increase in plant production mass of about 80%.

This is the central challenge and will not become easy to solve.

A solution may only be possible if all resources (including land reserves – mainly in Africa and South America) will be used including further progress in agricultural mechanization. Unfortunately political instability hampers the necessary actions in several poor countries.

1.1.3 The strategic role

This third field of responsibility of agricultural engineering is not so often addressed, as it has nothing to due with feeding, raw material or energy, nor with animals – but it is never-the less also very important.

The key point is, that agricultural mechanisation usually can reduce the number of working people in agriculture making possible that they can become productive in other areas of the national economy creating additional added value. This results in an increased GDP, as demonstrated by **fig. 1**. Agricultural mechanization is therefore in almost all developing countries the key technology to overcome poverty, suffering, low expectation of life, high illiteracy, high infant mortality, low level of infrastructure etc.

Summarized this means:

A low level in agricultural engineering usually means a high level of poverty.

This important relationship can also be explained well by the so called *Three Sector Model* as initially addressed by *Allan G.B. Fischer* [2] and *Colin Clark* [3] and directly after world war II by *Jean Fourastié* [4], a famous French Sorbonne professor.

Some data of Fourastié (1963) have been extracted and formed in a diagram by **fig. 2** for the US economy [1]. It indicates that around 1820 more than 70% of the working population had been engaged in agriculture in the United States and that a continuously reduced percentage took place over a long period of time.

Material of FAO, the "Country Reports" of the Club of Bologna [5] as well as international statistics and many publications confirm the message of the *Three Sector Model* for many countries. This model is not only useful for historical considerations but also a useful instrument for the evaluation of existing economies. Bangladesh – a poor country – can be addressed as a modern example: The number of working people engaged in agriculture has been about 85% in 1961 and was still 52% in 2006 according to [6]. For comparison: The value 52% was crossed in the United States already around 1875 – mainly due to the mechanization of cutting and threshing of cereals.

If we analyze the situation today, we can conclude that many countries could still improve their general economic level considerably by improving their agricultural mechanization.

In order to offer a real help for developing countries, the *Club of Bologna* members have supported technology transfer by presentations and recommendations since now 25 years.

A special highlight was and is the "Agricultural Handbook of Agricultural Engineering" a project under the auspices of CIGR, invented and edited mainly by members of the Club of Bologna (and printed by ASAE in USA in six volumes). Vol. III (Plant Production Engineering) is meanwhile even available in Chinese.

2. Globalization of agricultural machinery development and manufacturing

2.1 Expanded strategies for product development

The total turnover of the worldwide agricultural machinery production (including tractors) is estimated to be about 130 Billion US $ in 2014 [7].

Along with the globalization, agricultural machinery has become more and more international. This resulted in new strategies of increased world wide networking and cooperation as – for example – early addressed by members of the Club of Bologna [8].

While Henry Ford could capture the world market with only one tractor model – that was the famous FORDSON F (1917-28), **fig. 3**, – today's situation is completely different.

If worldwide market demands for tractors and farm machinery are analyzed, the come out is an extremely wide span of demanded specifications. It is by far not possible to cover them economically with only one machine nor with one machine family.

This was the reason to consider and to present a classification of worldwide demanded specifications – in a first step for the example "tractor transmission" 1999 in the CIGR Handbbook Vol. III, p. 140 and in a second step for the whole tractor in 2002 [9], **table 2.** The challenge for the product development is to cover the "technology levels" with a minimum number of components and platforms and thus a minimum number of living parts along with standardized interfaces. This principle cuts costs mainly regarding logistics – finally with benefits for the farmer. Implementations have been reported to the Club of Bologna for example by Gavioli for CNH [10]. A structured worldwide oriented product planning became a strong issue for all internationally active manufacturers of farming machinery.

2.2 Upper technology levels: from manual control to automatic closed loop control

The "cybernetic principle" as early addressed by Maxwell 1867 [11] and reviewed at the Club of Bologna meeting in 2012 [12], defines a closed loop control in which the actual value of a process is measured and fed back to be adjusted to a given target value, **fig. 4**. This type of control is usually more precise than a manual open loop control and offers – in addition – a higher comfort level for the driver. The strong technical trend in this direction is typical for the upper technology levels enabling "precision agriculture", based on two technical trends:

- the enormous *general progress in digital IT technologies* regarding functions, costs, availability and reliability [12 - 17];
- new *IT-friendly components* with interfaces for digital electronic CAN BUS control and information systems – see Club of Bologna meeting 1995, [16].

A vision of completely integrated IT technologies in agriculture has been demonstrated by Auernhammer and Schueller 15 years ago in the CIGR Handbook [17], **fig. 5**

The tremendous IT penetration offers basic holistic benefits for the farmer regarding:

- Productivity
- Product quality
- Traceability
- Sustainability
- Environment protection
- Energy efficiency
- Safety and comfort
- Farm management

Because of this megatrend in agriculture and agricultural mechanization, the well known CIGR Handbook, Volume I to V [18] was completed in 2006 by Volume VI [19] offering a comprehensive survey on all important aspects of information technology in agriculture.

2.3 The role of legal acts and standards

Several benefits have been initiated by legal acts or ISO standards – as several times reviewed by the Club of Bologna [20]. Two examples of progress may be mentioned [21]:

- The introduction of *rollover protection structures* could reduce the number of fatalities in Germany by about 95%";

- The *noise reduction* at drivers ear could be reduced from about 100-105 dB(A) to now only 70-75 dB(A) by cabs for full power/OECD eliminating hardness of hearing.

ISO standards replace more and more national standards thus being able to support global progress of agricultural mechanization in several aspects:

- by improved international *machinery development;*
- by improved international *machinery use* due to better *compatibility* for the farmer – even often when combining old and new machinery (PTO, 3-point hitch, drawbar, …):
- by *technology transfer* to developing countries.

The last benefit is often underestimated – a reason for ongoing treatment and recommendation by the Club of Bologna.

During the recent years, legal requirements for the upper technology levels have been concentrated on the reduction of Diesel engine emissions of tractors and mobile machinery. The now extremely strong limits within EU and USA [22] can only be met by expensive exhaust after treatment. This can double the costs of a simple Diesel engine and is – so far – not very popular. But it must be said, that the industry had no other choice meeting the limits and keeping in the same time the specific fuel consumption as low, as before.

3. Conclusions

Agricultural mechanization has a very long fascinating tradition from the very first simple hand tools to modern high sophisticated machinery, thus being a real driving force and piece of human civilization. The huge reduction of labour costs by mechanization could keep the prices low for staple food such as cereals. In addition, whole economies could benefit from increased labour productivity as people could be transferred for value adding outside agriculture reducing poverty and increasing national welfare in all areas of the economy. This is still a goal for developing countries and underlines the mission of the *Club of Bologna*.

The 21th century came up with dramatic challenges for agriculture und thus agricultural mechanization. The era of production surplus ended – further population increase must be met by agricultural production increase. This increase must be much higher than the population growth due to expected higher proportions of meet, energy and raw materials and expanded duties of environmental protection. As the variety of required technologies and power levels has dramatically been widened within the past decades, global product planning of machinery has to be structured meeting a wide span of locally oriented, graded technology levels.

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Fig. 1: Working people as employed in agriculture and corresponding GDP in US $. Diagram by L. Bodria, based on FAO data.

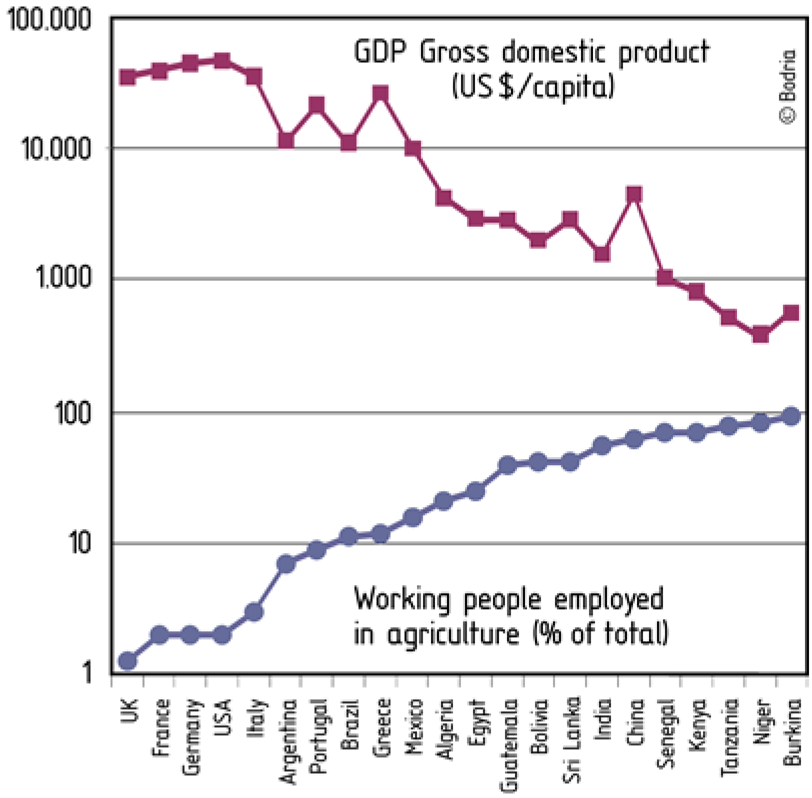

Fig. 2: Economy development of the United States by sectors [1] - data from Fourastié [4]

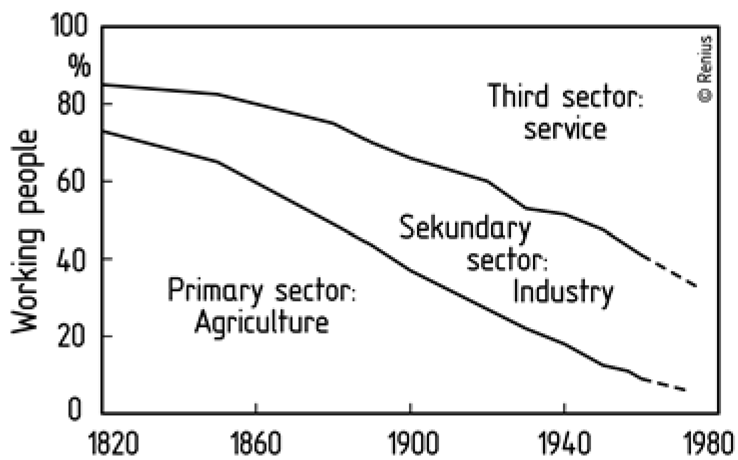

Fig. 3: Tractor FORDSON F (1917-1928) – achieving 1925 about 50% world market share with only one tractor model. Picture is taken on the Renius family farm "Albertshof" (Oranienburg, near Berlin, Germany) pulling a binder.

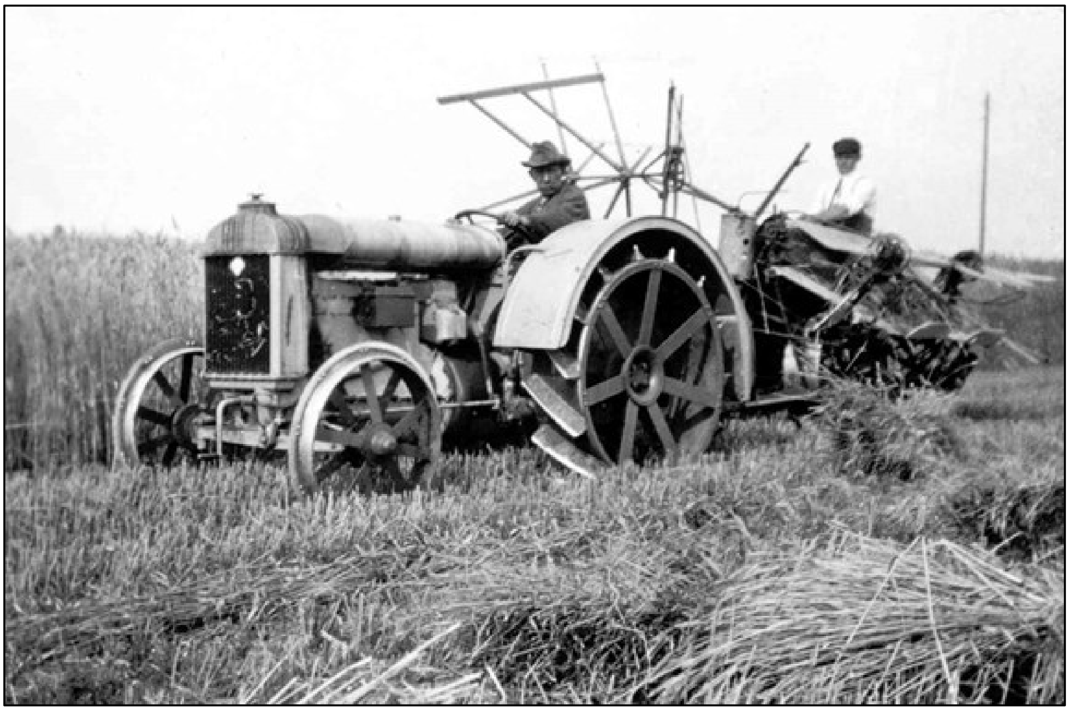

Fig. 4: Cybernetic principle of closed loop control being the central pillar of automation in modern precision agriculture (and other technical areas [12]).

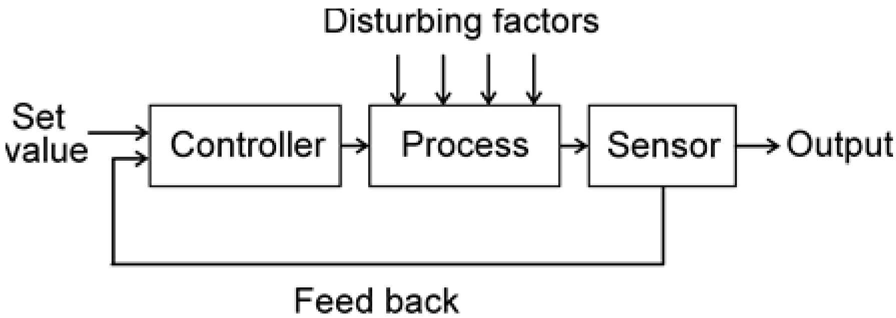

Fig. 5: Integrated farming system with IT penetration, early vision "Auernhammer" [17]

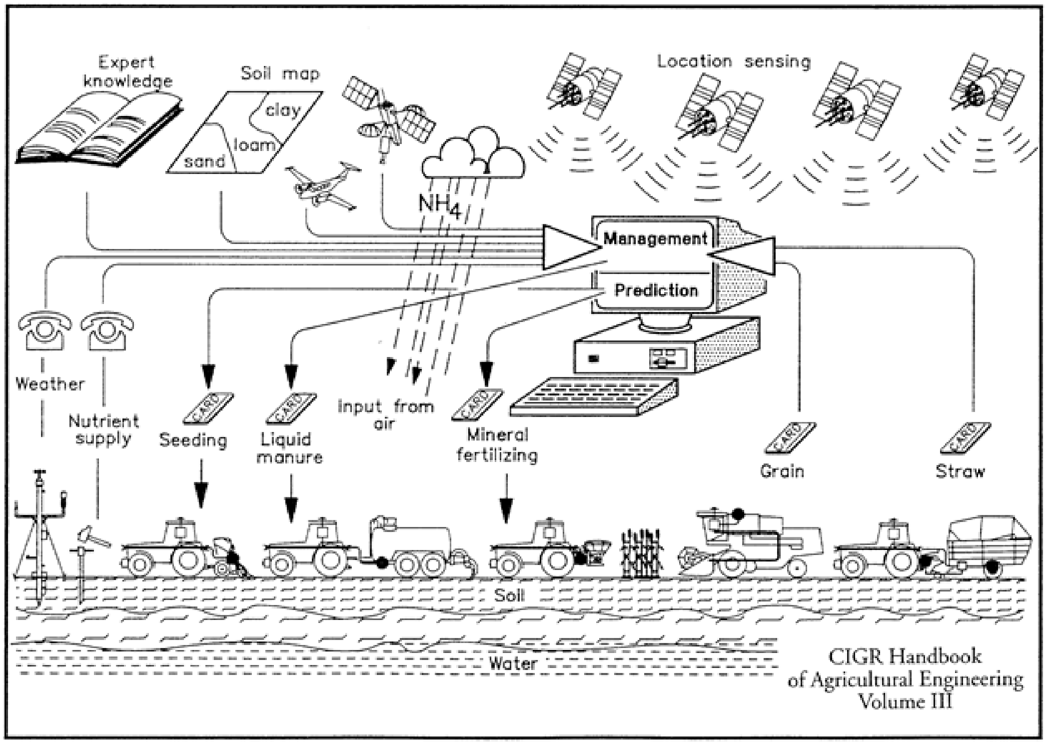

Table 1: Increase factors of productivity by mechanization, status 2008 [1]

- Milking machine ……..…..…..... *factor* 15
- Two horses ploughing ….……………... 25
- Small tractor ploughing ...…………….... 50
- Multi purpose tractor mowing …...…. 500
- Large tractor ploughing …………….... 1000
- Large combine …………………….…. 4000

Table 2: World wide demanded specifications for agricultural tractors: specifications classified by fife technology levels, proposal Renius 2002 [9].

	Nominal engine power			Wheel drive			Diesel engine					Drive transmission					PTO			Hydraulics				Cab			Elec-tronics		
Technology level	Low	Medium (40–80 kW)	High	Only rear-wheel drive	Four-wheel drive opt.	Four-wheel drive stand.	1 Cylinder	2 Cylinder	3 Cylinder	4 Cylinder	6 Cylinder	Very simple	Simple	Partial power shift	Full power shift	Infinitely variable	540/min	540 and 1000/min	3 or 4 speeds	Rear 3-point hitch	Remote Control	Rear & front 3-p. hitch	Load Sensing circuit	No cab	ROPS / low cost cab	Comfort cab	Not existing	Low cost concepts	High tech concepts
I	X			X			X	X		X		X					X			X				X			X		
II	X	X			X			X	X	X	X		X					X		X	X			X	(X)		X	(X)	
III		X	(X)		(X)	X			X	X	X			X				(X)	X	X	X	X			X	(X)		X	(X)
IV		X	X			X			(X)	X	X			X	X				X	X	X	X	X			X			X
V		X	X			X				X	X					X			X	X	X	X	X			X			X