CLUB OF BOLOGNA

THE 25 YEARS OF THE CLUB OF BOLOGNA

EVOLUTION AND PROSPECTS OF AGRICULTURAL MECHANIZATION IN THE WORLD

Editors:
Luigi Bodria and Marco Fiala

FEDER UNACOMA
Italian Agricultural Machinery Manufacturers Federation

ACCADEMIA DEI GEORGOFILI

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THE 25 YEARS OF THE CLUB OF BOLOGNA
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PREFACE

LUIGI BODRIA - PRESIDENT CLUB OF BOLOGNA

The use of increasingly advanced and more sophisticated tools has been the driving factor behind the social and economic evolution of mankind since our origins and, in particular, the close link between high levels of agricultural mechanization and a high quality of life is well known.
This axiom was founding concept behind the birth and development of the *Club of Bologna - Strategies for the Development of Agricultural Mechanization*, which I have had the privilege and honour to serve as President for the past eight years, and the twenty-fifth anniversary of which is celebrated in this volume
Twenty-five years of hard work and impressive growth, while the Club has seen its prestige increase continually due to the outstanding professionalism and active participation of its members. However, we cannot mention the Club of Bologna without recalling Prof. Giuseppe Pellizzi, its founding father and enthusiastic inspiring figure for seventeen years.
As a young assistant professor of agricultural machinery, he abandoned a promising professional career to devote himself entirely to research, having understood the intrinsic strategic value of agricultural engineering, at that time considered simply a minor branch of the agricultural sciences.
He became full professor at Milan University in 1968 and his intelligent commitment, love for research, determination and charismatic personality soon made him a leading figure in agricultural engineering at the national and international level. A firm believer in the fundamental importance of constructive dialogue and the exchange of ideas for the progress of research, he was constantly committed to internationalization, promoting various initiatives intended to foster supranational exchanges and collaboration.
His presidency of the CIGR from 1991 to 1994 led to a lasting revitalization of the Commission. He was a cofounder of the European Community Club of Advanced Engineering in Agriculture, ECCAEA, which has now evolved into ENGAGE, the strategic division of the European Society of Agricultural Engineers, EurAgEng.
Hence the origin of the Club of Bologna, where he was able to bring together and strongly motivate the foremost leading personalities in the agricultural engineering sector, from both industrialized and emerging countries.
It is thanks to his enthusiasm and dynamism that the Club of Bologna has successfully pursued its aims throughout the twenty-five year history recounted here.
Sincere and heartfelt thanks must also go to the Agricultural Machinery Manufacturers' Federation FederUnacoma, which immediately appreciated the project's immense scientific and cultural value, and has provided the necessary economic and organizational support which has made it possible.

INTRODUCTION

GIANPIERO MARACCHI - PRESIDENT ACCADEMIA DEI GEORGOFILI

The close ties between the *Accademia dei Georgofili* and FederUnacoma – the National Federation of Agricultural Machinery Manufacturers (formerly Unacoma - National Union of Agricultural Machinery Manufacturers) - have gradually strengthened over the years, leading to the signing of a Protocol of Understanding between the two institutions.

The agreement provides for joint promotional activities in the agricultural mechanization sector and also calls for joint actions through direct contacts between local Sections of the Academy and the Club of Bologna, for the organization and implementation of initiatives, in association with third parties where appropriate, to promote the agricultural cultural heritage and scientific and technological innovations that impact on farming and rural areas, also with regard to the training of young researchers.

As early as 1995 the Accademia dei Georgofili accepted Unacoma's invitation to collaborate on the publication of the volume "*50 Years of Agricultural Mechanization – History and the Challenges"* with the assistance of distinguished Members of the Academy.

The Academy has enthusiastically agreed to repeat this cooperation this year for the writing of the volume *"The 25 Years of the Club of Bologna – Evolution and Prospects of Agricultural Mechanization in the World".* It is worth remembering that the Club, founded by Emeritus Academy Member Prof. Giuseppe Pellizzi under the auspices of the CIGR (International Commission of Agricultural and Biosystem Engineering) led on to the joint establishment of close collaboration with other international institutions.

Thanks to the contributions of illustrious experts from various countries, the volume on the 25 years of the Club, with its seven chapters on mechanization, not only recounts the organization's activities but also provides detailed analyses of the evolution of, and especially future prospects for, agricultural mechanization, driven by strong innovation in the sector's products and processes, led by both the world of science and farm machinery manufacturers.

These surveys are presented broken down by geographical areas, reflecting the different territorial and socioeconomic conditions across the globe. The contents of the text mirror the aims of the Accademia dei Georgofili and are an implicit confirmation of the two institutions' continuing commitment to the promotion of agricultural development.

INTRODUCTION

MASSIMO GOLDONI - PRESIDENT FEDERUNACOMA

Research and experimentation are two interconnected and fundamental factors for the development of all human activities and essential for the evolution of the industries manufacturing machinery, equipment and associated components for agriculture and gardening, sectors represented in Italy by Unacoma beginning in 1945 and then by FederUnacoma. The federation I am honored to preside over organized an international symposium for the EIMA 1987 edition - the review of the sector created in 1969 - in collaboration with the internationally renown academic and agricultural engineering researcher, Prof. Giuseppe Pellizzi, a figure always close to Italian manufacturers in the sector and a good friend of the association which represents them. The purpose of the symposium was to take a snapshot of the state of the art and prospects for research in the global field of agro-mechanics with the participation of representatives from various nations involved in this area.

The event was extremely interesting due to the number and quality of the contributions advanced and comparisons drawn which then laid the groundwork for the formation of a body of academic experts meeting periodically to evaluate strategies for furthering agricultural mechanization: the Club of Bologna. The Unacoma of the time immediately backed this new project and since 1989, when the Club's first official meeting was held, has sponsored the body and worked in collaboration with its presidents over the years to organize the meetings promoted.

Over the twenty-five years of activities celebrated in this volume, the Club has pursued a long course promoting and accompanying the most recent evolution of machinery and equipment for agriculture under the sign of electronics and eco-sustainability. Many other goals are also under study so that the Club can continue working with inspiring leadership.

And then it gives me great pleasure to share in the publication of this text with the Accademia dei Georgofili, an emeritus institute which counts among its members marvellous inventors of *revolutionary* mechanical solutions and has signed a collaboration agreement with FederUnacoma for joint work aimed at the promotion and growth of various agricultural models in Italy and around the world.

CHAPTER 1

THE CLUB OF BOLOGNA

CHAPTER 1
THE CLUB OF BOLOGNA

BY **LUIGI BODRIA** (ITALY), **MARCO FIALA** (ITALY), **KARL T. RENIUS** (GERMANY)

ORIGINS

The idea to create the *Club of Bologna* arose on the wave of the high interest inspired in the '70s by the Club of Rome's report *The Limits to Growth* (1972) and the friendship between Giuseppe Pellizzi and Umberto Colombo, member of the Club of Rome and co-author of the Club of Rome's fourth report, *Beyond the age of waste*, published in 1978.

The Club of Rome was only very little engaged in the role and global importance of agricultural mechanization so that first ideas arose that the agricultural machinery and mechanization sector, being so central to human development, could also benefit from a free and open exchange of ideas between leading personalities in its community. Pellizzi launched the proposal at the end of the international symposium on *"Research and Information-Spreading on Innovations for Agriculture and Industry in the Year 2000"*, organised at the EIMA (International Exhibition of Agricultural Machinery Industries) in 1987 under the auspices of the Italian Agricultural Machinery Manufacturers' Federation, then known as UNACOMA.

During the closing session, attended by a large number of foreign researchers, the proposal took shape for a regular forum for discussion amongst experts from the various countries on the state of the art in the development of agricultural mechanization, from the technology development as well as from operational and scientific points of view.

The idea was discussed more in detail by a small group of directors and high level representatives from the leading international research centres (**Figure 1**) and received a very favourable reception from UNACOMA, which offered to sponsor the organisation and management costs of the project.

Figure 1 - Representatives of leading research centers discuss the proposal of Club of Bologna: (from the left) K.T. Renius, Technical University of Munich (D); J. Lucas, CEMAGREF (now IRSTEA) (F); L. Lisa, National Research Council (I); E. Manfredi, University of Bologna (I); J. Matthews, NIAE, Silsoe (UK); G. Ambrogi, director of UNACOMA; G. Pellizzi, University of Milan (I); L. Brega, Unacoma Press Office

This led, in November 1988, to the foundation of the *Club of Bologna*, an independent, non-profit, scientific and cultural organisation intended to provide a permanent centre for the study and analysis of the evolution and characteristics of agricultural mechanization at international level, in order to discuss and define the most appropriate development strategies according to individual countries' specific characteristics and possible future international scenarios.
An organizing committee was appointed with representatives from the top research centres in France, Germany, Italy, the United Kingdom, Japan and the United States, who also provided the first Management Committee, comprising:

- G. Pellizzi, head of Agricultural Engineering Institute, University of Milan (I);
- G. Ambrogi, director of UNACOMA (I);
- R. Hegg, head of Agricultural and Biological Engineering Department, Clemenson University, North Carolina (USA);
- O. Kitani, chairman of Dept. of Agricultural Engineering, University of Tokyo (Japan);
- L. Lisa, head of Agricultural Mechanization Instute of the National Research Council (I);
- J. Lucas, head of agricultural machinery division of CEMAGREF (now IRSTEA) (F);
- E. Manfredi, head of Agricultural Machinery Institute, University of Bologna (I);
- J. Matthews, head of AFRC (former NIAE) Silsoe Reseaarch Institute (UK);
- K.T. Renius, head of Agricultural Machinery Dept., Technical University of Munich (D).

The newly formed Management Committee, in agreement with UNACOMA, elected Giuseppe Pellizzi as President.
In its internal rules, the *Club of Bologna* defines its mission as

> *"the study and definition of strategies for the development of agricultural mechanization worldwide, taking into consideration technical, economic and social advances and changes in agriculture on an international level".*

These aims are pursued

> *"through exchanges, discussions and sharing of experience and knowledge of scientists, researchers, technicians, managers, agricultural machinery manufacturers and farmers who are concerned with the fundamental problems in this field, on the basis of collected pertinent information, specific and general studies and analyses, and on the refinement and development of logical concepts of a scientific and political nature".*

Membership of the Club is open to leading professionals holding senior positions in the various countries and in the various areas of agricultural machinery and mechanization, who undertake to attend the Club's meetings and contribute the weight of their experience to its proceedings.
Membership applications are subject to the Management Committee's approval and members are required to meet their own travelling expenses for attendance at Club meetings, while UNACOMA covers organisational and hosting costs at the meeting location.

CHAPTER 1
THE CLUB OF BOLOGNA

The fast growth and success of the *Club of Bologna* was to a large extend a result of the wide spread visions, engagements and nets of its originator and first President, Giuseppe Pellizzi. It is his merit to create a friendly and fruitful atmosphere enabling investigations and discussions free of influences of all political borders. He worked enthusiastically building up an outstanding group of leading personalities from both industrialised and developing countries, combining professional expertise with personal friendship and running the Club like a single large family.

The first Members' Meeting of the *Club of Bologna* was held on November 8 and 9, 1989, together with the EIMA's twentieth anniversary celebration, with the following topics:

- *Agriculture and Mechanization after the Year 2000 (presentation of preliminary analyses)*, with report by Management Committee members: O. Kitani, J. Matthews, J. Lucas and G. Pellizzi covering the situations in their respective countries, together with Oleg Marchenko of the All Union Research Institute for Mechanization in Agriculture, Moscow, for the USSR and Hua Guozhu of the Chinese Academy of Agricultural Mechanization Sciences, for the People's Republic of China;
- *Process and Production Innovation in Agricultural Mechanization*, with reports again by two members of the Management Committee, K.T. Renius and J. Lucas, and a contribution from Dario Casati, an economist of the Agriculture Faculty of the University of Milan.

Since then, the *Club of Bologna* has met annually on a fairly regular basis, mainly at Bologna during EIMA until this became a biennial event alternating with AGRITECHNICA, Hanover. After this change in 2008, an agreement was reached with the DLG (German Agricultural Society).

The DLG, respecting the Club's work, kindly offered, to host meetings within the AGRITECNICA show. Therefore, since then the Club has met at EIMA in Bologna in even years and at AGRITECHNICA in Hanover in odd years, making Germany the Club's second key centre of reference.

From the very first meeting, the importance was appreciated of extending the Club's area of interest to focus more strongly on the problems related to appropriate mechanization in developing countries. A close working relationship was therefore formally established with the FAO and UNIDO, which delegated two member experts to the Club. The high importance of developing countries was also one reason to invite Yoshisuke Kishida, President of Shin-Norinsha Co. Ltd. and chief editor of the well known Japanese journal AMA – Agricultural Mechanization in Asia, Africa and Latin America, to become a Club member.

In the following years the *Club of Bologna* continued to grow and develop for seventeen years under the enlightened leadership of its promoter and first President, Giuseppe Pellizzi, and subsequently thanks to the commitment and strong enthusiasm of the succeeding Presidents, Ettore Gasparetto from 2004 to 2008 and the current President, Luigi Bodria, both contributing to a continuing recognition of the Club. An important role in this process has been played by the Club's General Secretary, Marco Fiala, who has been the driving force of its organisation over so many years.

The *Club of Bologna* currently has almost a hundred members, representing 37 different countries, from worldwide research centres, universities, international organisations, manufacturers and industry associations.

The current Management Committee comprises 17 members from 10 different countries, including three representatives of industry associations, another one from an important corporation and one from the press (**Table 1**).

Table 1 - Current composition of the Management Committee

President	Luigi BODRIA	Dept. of Agricultural and Environmental Sciences, University of Milano	Italy
General Secretary	Marco FIALA	Dept. of Agricultural and Environmental Sciences, University of Milano	Italy
Member	Marco PEZZINI	FederUnacoma Delegate	Italy
Member	Ulrich ADAM	CEMA Delegate	Germany
Member	Paolo BALSARI	Dep.t of Agricultural, Forestry and Environmental Economics and Engineering, University of Torino	Italy
Member	El Houssine BARTALI	Hassan II Inst. of Agronomy and Veterinary Sciences (IAV), Rabat	Morocco
Member	Yoshisuke KISHIDA	AMA, Agricultural Mechanization in Asia, Africa, and Latin America, President of Shin-Norinsha Co. Ltd	Japan
Member	Oleg MARCHENKO	VIM - All-Russia Research Inst. Mechanization in Agriulture.	Russia
Member	Luis MARQUEZ	Dept. of Agricultural Engneering, Polytechnic University of Madrid	Spain
Member	Axel MUNACK	Inst. of Agricultural Technology and Biosystems Engineering, Federal Research Institute for Rural Areas, Forestry and Fisheries	Germany
Member	John POSSELIUS	CNH Industrial	USA
Member	Karl RENIUS	Inst. of Agricultural Machinery, Technical University of Munich	Germany
Member	Alain SAVARY	AGRIEVOLUTION Delegate	France
Member	John SCHUELLER	Mechanical and Aerospace Engineering Dept., University of Florida	USA
Member	Gajendra SINGH	Doon University, Dehradun	India
Member	Bassam SNOBAR	Dept. of Agricultural Mechanization, Jordan University of Science and Technology	Jordan
Past President	Ettore GASPARETTO	Dept. of Agricultural and Environmental Sciences, University of Milano	Italy

This board is responsible of organising the Club's meetings, selecting topics of interest for the development of agricultural mechanization at worldwide level, mandating its members and, if appropriate, looking for external experts for invited key-note reports on the selected subjects.
Presentation of the key-note reports is followed by in-depth discussion, in which the Club members are invited to contribute meaningfully on the basis of their specific experience and professional expertise, leading to drawing-up the Club's conclusions and recommendations for distribution to political bodies, industry organisations, researchers, manufacturers, etc.

The Proceedings of Club meetings, initially printed in volumes, are now available to everyone as e-documents at www.clubofbologna.com.

TOPICS COVERED

Over the last twenty-five years, the working sessions at the Club's members' meetings have discussed a large number of widely varying topics, addressing the most important technical, functional and organisational aspects of the evolution and development of agricultural mechanization worldwide (**Figure 2**).

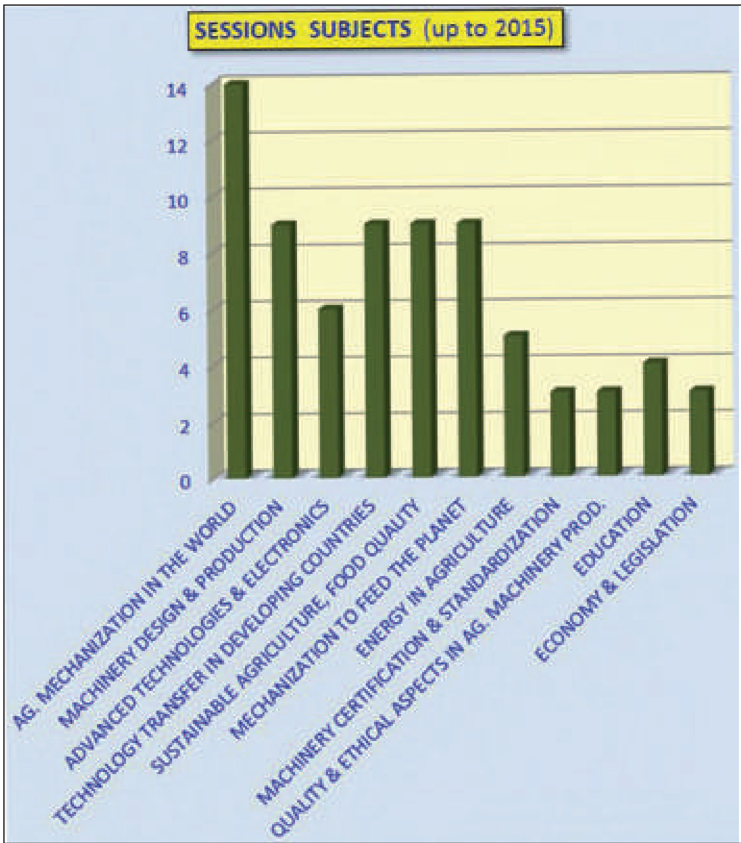

Figure 2 - Topics covered in the various Club of Bologna Meetings

The most addressed subjects have been those being closely related to the specific issues of *mechanization*, the *design and production of agricultural machinery* as well as the application of emerging, *advanced technologies*, to which a total of 25 working sessions have been dedicated.

The strategic role of *agricultural mechanization* in countries' development has received a great deal of attention, highlighting the close relationship between the reduction in the numbers employed in agriculture generated by progress in agricultural engineering and overall improvement of the socio-economic conditions of the country.

Since the first meeting in 1989, the members have returned to this topic repeatedly over time, emphasising the great complexity of the situations in the various countries and the importance of the latest in-

Figure 3 - Meeting 2009 in Hanover (Agritechnica)

formation technologies in defining models of mechanization appropriate to conditions in different regions. Several sessions have also addressed technological developments in the main operations in the field, concentrating in particular on the machines of fundamental importance in functional and environmental terms, discussing processes such as soil preparation, the application of chemical and organic inputs and irrigation.

In two working session the role of contractors was analysed underlining their growing contribution in farming operations, both in industrialized and developing countries, in order to reduce costs and allow the utilization of most appropriate equipment.

Another topic to receive considerable attention has been the *design and production of agricultural machinery*, which over time has become highly sophisticated, requiring suitable criteria for the control and optimisation of the industrial production process. To achieve this, several working sessions have discussed both the need for close cooperation between research institutions and industry, and coordinated management criteria of design and production (i.e. "simultaneous engineering" and "platform principle") in order to reduce total first costs.

In line with its mission to define and disseminate scientific principles for the design of agricultural machinery, the Club decided to publish the *"CIGR Handbook of Agricultural Engineering"* in association with the CIGR

(Commission International de Genie Rural), edited in 1999 by Osamu Kitani, then President of the CIGR and a respected member of the *Club of Bologna*. This was a joint project undertaken by more than 150 international experts, the majority of them members of the Club.

This six-volume handbook covered all fields of agricultural engineering, providing a comprehensive collection of the basic principles and new technologies in the discipline. Published in the USA by the American Society of Agricultural and Biological Engineers (ASABE), it is now also available in an e-version. In order to enlarge its technology transfer impact, volume III of the Handbook has been translated into Chinese in 2005 with the help of the Chinese Academy of Agricultural Mechanization Sciences (CAAMS) and the Chinese Society for Agricultural Machinery (CSAM).

Information and automation technologies have so dramatically been developed over the past decades, that they became not only a key subject within the *Club of Bologna*, but also a volume VI of the CIGR Handbook on "Information Technology", edited by a *Club of Bologna* member and published in 2006 (also by ASABE). This was meanwhile translated to Turkish in 2015.

Summarising this, the CIGR Handbook can be called to be an outstanding example for the global networking within the *Club of Bologna* in favour of the whole international community.

Other topics widely studied by the Club's experts include *technology transfer to developing countries, environmental sustainability and product safety*.

With regard to *technology transfer*, several sessions have analysed mechanization systems appropriate to the small farms of developing countries and possible strategies to encourage the development of mechanization in these areas, underlining the fundamental importance of technology transfer in a context of close cooperation between private players and local governments.

Concerning *environmental sustainability*, the Club had already addressed environmental protection issues as early as in the 1990's as a key factor in the future development of agricultural mechanization and machinery. A number of meetings addressed over the years the subject of sustainability together with that of food safety and traceability, since environmental and consumer safety are considered essential strategic factors of future farming technologies.

All the topics mentioned so far were recently combined and coordinated as part of the large general head line "Mechanization to Feed the Planet", addressed at the two last Members' Meetings and finally presented at the EXPO Milan 2015 International Exposition.

Energy in agriculture is another subject to which a great deal of attention has been paid due to its implications for the reduction of energy dependence on fossil fuels and the introduction of high-return production chains into the farming sector. This topic was discussed in several meeting since 1992, including the possibility of using liquid and gas bio fuels for internal combustion engines. These meeting's highlighted both, the possibilities of designing modified or new engines, and the questions of improvements in growing methods for energy crops and their general role in faming systems. The potential offered by the use of vegetable oils from oilseed crops has early been recognised by the Club and has contributed to developing reliable technical solutions.

Figure 4 - Meeting 1996 in Bologna (Eima international): (from the left) K.T. Renius, member of the Management Committee; A. Celli, President Unacoma; G. Pellizzi, President Club of Bologna; O. Kitani, member of the Management Committee

In 2011 the whole meeting was dedicated to energy, examining aspects of the biomass-to-fuel production chain: the role of the farming sector, analysing the case of Brazil with the growing of sugarcane for bio ethanol; and the contribution of biomass farming and forestry by products for biofuel production, with a particular focus on biogas and wood and a 2nd generation of bio ethanol. As the final link in the chain, tractor manufacturers described their current and future projects in this area.

Regarding the Club's permanent attention to the expectations of agricultural machinery manufacturers and the requirements of the related markets, the topic of *machinery certification and standardisation* was another subject of analysis, discussion and recommendations. It was tackled in general terms first in 1998, considering on the one hand the need to harmonise the methods used for testing machine performances, and on the other the importance of reliable certifications.

The global support of standards was and still is a typical strategy of the *Club of Bologna* as it makes a lot of sense to move standard developments more and more from a national to an international level. The benefits are obvious: harmonised interfaces, globally accepted test procedures, human relations, safety, emissions, communication systems, sustainability, recycling and others; and as a "by product" knowledge transfers to developing countries as well. The Club returned to this subject at the Hanover meeting in 2013, dedicating a whole Members' Meeting to it, including presentations of the viewpoints of the leading international organisations working in this sector.

Figure 5 - Meeting 2014 in Bologna (EIMA International)

This will remain a very important strategic issue also for the coming years to reduce the remaining gaps between industrialised countries and to support technology transfer to developing countries.
Some fascinating topics addressed the production process for agricultural machinery under the innovative *total quality* approach and the definition of a *code of ethics* for its manufacture, underlining the requirement for harmonised, documented rules to ensure the manufacture of machines that meet farmers' expectations in terms of durability, performance, safety, reliability and environmental sustainability.
The *Club of Bologna* was also working on curricula of agricultural engineering *education* analysing the related educational programs of the main European universities being active in this field and looking for reasonable harmonisations.
Regarding the competitiveness of the agricultural machinery industry within the European Union, several meetings of the Club addressed the implications of *economy and legislation.* It was and still is the aim, to support a fruitful development and harmonisation with a realistic sense of proportion and practical realization.

THE CLUB TODAY

In view of the growing importance of agricultural mechanization in delivering progress in farming and environmental protection, and with the aim of developing positive partnerships, the *Club of Bologna* has signed a Protocol of Understanding with the *Accademia dei Georgofili*, an historical Italian institution founded more than 250 years ago, which works to promote scientific progress in agriculture and rural development. The protocol aims to encourage joint activities and the realisation of initiatives related to enhancement of scientific and technical innovation of interest to farming, and for the training of young farmers.
As part of this programme, in order to promote young people's interest for research on the issues of agricultural mechanization, the *Club of Bologna* and the Academy of Georgofili announce every two years the Giuseppe Pellizzi Prize, kindly sponsored by the Italian FederUnacoma.
The competition is open to young people who have received a PhD in the previous two years, and prizes are awarded to the three best theses on the subject of agricultural machinery and mechanization. The winners

Figure 6 - Award ceremony of the first edition of the Giuseppe Pellizzi Prize (Bologna 2012) awarded to: Eva Maria Báguena Universidad Politécnica de Madrid, Spain; Sven Peets, Harper Adams University, United Kingdom; Parish Nalavade, Asian Institute of Technology, Thailand

receive a cash prize and are also invited to attend the Club's Members' Meeting, where they get the chance to present the results of their research to the whole Club.

During the last two years, the *Club of Bologna* has dedicated its attention to the topic put forward by the *Expo 2015 International Exposition* being prepared in Milan, which, with its motto *"Feed the Planet, Energy for Life"*, focused the scientific and political debate on future food security and the right of a growing world population to sufficient, safe food.

The relationship between mechanization and food production was obviously a very exciting subject for the *Club of Bologna*, and so the XXV Members' Meeting, held in Bologna in 2014, was entitled *"Agricultural Mechanization: the Engine of Energy for Life"* and set out to assess and discuss the role and lines of development of agricultural mechanization in relation to the absolute imperative so clearly stated by the Expo motto.

The reports of the 2014 meeting have been presented by leading personalities from research (Bodria, Renius, Schueller, Singh, De Baerdemaeker, Oberti), important organisations like VDMA (German Mechanical Engineering Industry), UNIDO, FAO and CEMA (European Agricultural Machinery Industry) and individual representatives from the industry (Lely, CNH). The presentations highlighted the close links between socio economic development and agricultural mechanization and pointed out strategic development lines which agricultural

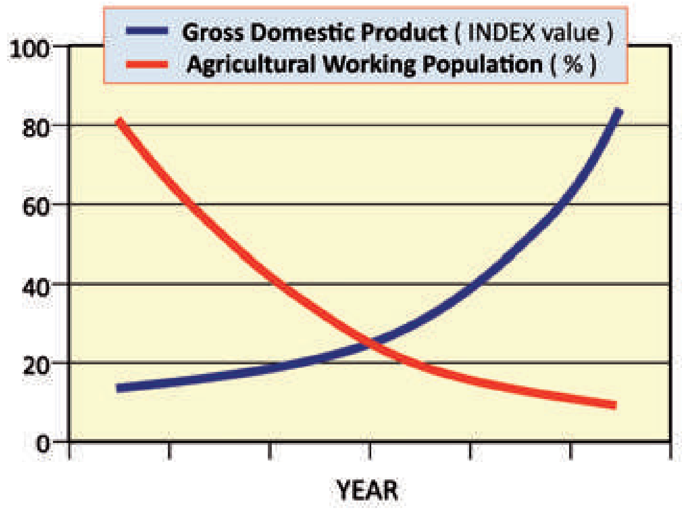

Figure 7 - Relationship between active population in agriculture and national Gross Domestic Product

mechanization should follow to face the food security challenges of the coming decades and to help developing nations rising their prosperity and welfare.

It was reminded that it was the birth of agriculture that started the long process of human evolution and that all the phases in the progress of humanity have been closely linked to developments in farming. Agricultural mechanization has played a key role in this process by improving yields, delivering higher quality levels and, above all, dramatically increasing the productivity of human labour to the point that the number of people employed in farming has now fallen in the developed countries to only 1,5-4% of all working people compared to 70-75% in the early nineteenth century.

The social economic advantages are not only an increased food production, better food quality and lower food prices, but also a general increased standard of living: agricultural mechanization reduces the number of working people in agriculture making it possible that they can become productive in other areas of the national economy creating additional GDP (**Figure 7**). This leads finally to a generally increased prosperity and social welfare, as several investigations of *Club of Bologna* members could confirm.

After discussing the tasks that mechanization has successfully fulfilled in past years, the presentations highlighted that *environmental sustainability* and *appropriate mechanization for developing countries* are the two major future lines along which agricultural engineering must develop. To face the challenge of the Expo motto *"Feed the Planet, Energy for Life"* and considering that the food need is forecast to rise by more than 60% in the next twenty-five years, agricultural mechanization must be able to:

- combine the high levels of productivity now possible in highly mechanized countries with environmental sustainability;
- help to increase food production in areas where poverty and hunger persist.

With regard to the first topic, the amazing development of automation and electronics have brought outstanding machinery and machinery system improvements in terms of availability, functions, costs, reliability and sustainability, confirming predictions made fifteen years ago by Club members Auernhammer and Schueller in the CIGR Handbook Vol. III.
The integration of GPS in agricultural machinery capable of providing the machine's position to within a few centimetres, sensors capable of "reading" environmental and crop conditions, and more and more sophisticated automation and information processing systems have led to the development of what is known as Precision Farming, an integrated system for the optimisation of machines' operations in the field on the basis of local characteristics, local positions and crops' real requirements.
Therefore, agricultural machines are gradually being transformed from "mechanical equipment" that increase the capacity and quality of human labour into "smart systems" that can automatically adapt to the real needs of field locations, offering the basis for a major step forward towards the environmental sustainability of agricultural production systems.
The possibility to tailor in a site-specific way chemical and fertilizer application using prescription maps together with advanced systems of automatic machine guidance and operative control may reduce the amount of fertilizers and pesticides distribution by 10% to 50%, depending on crop and local conditions, from which important savings have already been realised. High accuracy automatic guidance systems avoid overlaps between passes and increase the working speed, thus reducing by 5-10% both fuel consumption and chemical application.
Therefore it is widely acknowledged that the total application of chemical fertilizers and fuel consumption per hectare could already be reduced in the highly mechanized farming systems within the recent decade.
One limited resource of the future is seen in the availability of fresh water. Smart irrigation technologies and management systems following real soil and crop needs can allow important water saving of 15% to 40%.
On the second topic, the reports revealed the importance of the development of appropriate agricultural mechanization reducing malnutrition and poverty. The experience of countries that have succeeded in reducing hunger and malnutrition shows that economic growth originating in agriculture is the first important step of improving also the general standard of life from poverty to prosperity and welfare.
This means that research, industry and international organisations must all commit strongly to facilitating the development of agricultural mechanization appropriate to the conditions of the most underdeveloped areas, allowing:

- increases in the efficiency and productivity of farming operations;
- reduction of losses after harvesting;
- easier transport to market systems;
- improve quality control systems.

Figure 8 - Open Meeting of Club of Bologna "Farm Machinery to Feed The World" held in Expo Milan 2015: (from the left) M. Pezzini, FederUnacoma; P. Pickel, John Deere; L. Bodria, President Club of Bologna; D. Caccioni, Chairman; P. De Castro, EU Parliament; A. Olliver, CNH Industrial; D. Scanavino, President Italian Farmers Confederation

In the light of the above, the *Club of Bologna* decided, in partnership with the Accademia dei Georgofili, to hold a public Open Meeting at the ***Expo Milan 2015 Universal Exposition*** entitled *"Farm Machinery to Feed the World"* in order to contribute with the fundamental strategic role of agricultural mechanization to the Expo 2015 motto, "Feed the Planet, Energy for Life".
After an introductory report by Club President Luigi Bodria, underlining the way in which the major innovations in agricultural mechanization during the last few years took place combining agricultural production and environmental sustainability, the Deputy President of the Accademia dei Georgofili, Michele Stanca, explained the huge opportunities offered by agricultural genetics, with the latest studies. It was amazing to hear the long term forecast that the genetic potential of basic crops may allow future yield duplication in tons per hectare. After this, Karl Renius and John Schueller introduced the latest developments and innovations of tractors and agricultural machinery which improve efficiency, sustainability and global industrial product planning processes, while Josef Kienzle and Gajendra Singh discussed the big improvements made by mechanization in Asian countries and the need to facilitate a similar process in African states.
The conclusions and recommendations at the end of the meeting were brought into the document *"Milan Charter for Mechanization"* which has been approved by the Expo Scientific Committee and included among the 120 official contributions to the "*Milan Charter*". This is the official legacy of Expo 2015 and was delivered to Secretary-General of the United Nations, Ban Ki-moon by the Italian Minister for Agriculture, Food and Forestry Policies, Maurizio Martina, on World Food Day, held in Milan on October 16 2015.

The *"Milan Charter for Mechanization"* strongly stresses the need of:

- the central role of agricultural production and related technologies in order to guarantee everyone the availability of adequate and safe food supply;
- research in the area of agricultural machinery and mechanization, and more generally, of agro-food technologies;
- appropriate measures assessing environmental aspects of agricultural mechanization including criteria of sustainability and traceability in co-operation with national and international authorities;
- the development of an appropriate agricultural mechanization consistent with the local socio-economic conditions to promote agricultural production and rural development in developing countries and to enable at the same time the first step to get poor nations economies up to national prosperity and welfare;
- much higher political priority and attention paid to research, education, extension, personal networking, information supply and international co-operation in agricultural mechanization regarding the huge importance of this discipline for future mankind.

CHAPTER 2

AGRICULTURAL MECHANIZATION AND THE ROLE OF TRACTORS

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BY **KARL T. RENIUS** (GERMANY)

PREFACE

Global sales for all agricultural machinery accounted for about 110 billion US $ p.a. as an average for 2013/14/15 [73]. For about one hundred years, the tractor has been the most important piece of machinery, with at least 40% of global sales value, meaning about 44 billion US $ p.a. for 2013/14/15. Sales in many developing countries represent even 50% or more, but in the industrialized countries this is often only about 35%, due to specialized self-propelled harvesting machines replacing former tractor-implement combinations.

The tractor is necessary for feeding the world also in the future [9]. However, this is not the only aspect of its importance as agricultural mechanization; it is also a key technology for making whole national economies grow in prosperity and social welfare – which still has huge potential in emerging countries.

The following paper briefly addresses the economic background, outlines global tractor development strategies, includes some management principles and analyses basic concepts and technology trends.

AGRICULTURAL MECHANIZATION – ITS GENERAL ECONOMIC IMPORTANCE

Three fields can be identified according to [60]:

- The *classical role* : mechanisation of plant and animal production, storage and processing in order to feed the planet (can also include aquaculture growing)
- The recently added *environmental role* : mechanisation of raw material & clean energy production and landscape maintenance in order to safeguard the planet
- The *strategic role* : mechanization to increase labour productivity in agriculture, in order to free labour power to develop other areas within national economies

The classical and the environmental role

Both are addressing the fundamental human needs of having enough food, energy and raw materials – and thus facing the expected population growth and limited resources as well.

Agricultural mechanization influences productivity through two basic farming factors: *land productivity* and *labour productivity.* Its influence on *land productivity* is not dominating, but is one of several important factors (**Table 1**).

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

Table 1 - Factors affecting agricultural land productivity for given field sites, soil types and climate conditions

Mechanization benefits for land productivity are – for example – improved yields, higher quality levels, reduced input of materials, reduced human workloads, reduced losses and increased information levels. The old methods of harvesting cereals (as still used in many developing countries) often have losses of 20 or even 30% (FAO), while the losses of a modern combine work out at only about 1.0-1.5% under usual conditions.

Influence on *labour productivity* is considerably higher – it is even by far the most dominant. The following three examples may indicate the huge progress by mechanization as compared to manual labor [9, 60]:

- Small tractor ploughing productivity increase by factor 200
- Large tractor ploughing productivity increase by factor 1000
- Large combine harvesting wheat productivity increase by factor 5000

As a very positive consequence, world market prices for basic agricultural products became lower and lower, although labour costs and many other price levels increased. In highly developed countries, people spend today only about 15% of their income to buy food (as an average, beverages included). This figure has never been so low and food has never been offered in such a good quality – both mainly thanks to agricultural mechanization.

A certain conflict is that the production of energy and raw materials is in competition with food production – same for the expected over proportional increase in animal production. This has led to forecasts that the relative plant production increase must be higher than the relative population increase.

While an increase from 7.1 to 9.5 billion people (as expected from 2014 to 2050 by FAO) means 34%, several experts estimate a demand increase in plant production of at least 60%. Gavioli stated in his recent vision to the *Club of Bologna* [15], that perhaps "only" plus 50% may be sufficient, if the food losses are substantially reduced for both the agricultural and post harvesting processes and the food being wasted by the consumer. In any case, the challenge is huge –also as regards the declining area of arable land [2].

The strategic role

Any type of mechanization and automation can improve the level of a national economy, for example measured by its Gross Domestic Product (GDP). Mechanization of agriculture is the typical first step as it can usually reduce the number of working people in this sector, enabling transfer of manpower to other areas of the national economy, creating additional added value (increasing the national GDP) and finally levelling up welfare and prosperity. This very important relationship could be demonstrated by the *Club of Bologna* with its "Country Reports" [40] and updated by a report to the *Club of Bologna* at EXPO 2015 in Milan [64] (**Figure 1**).

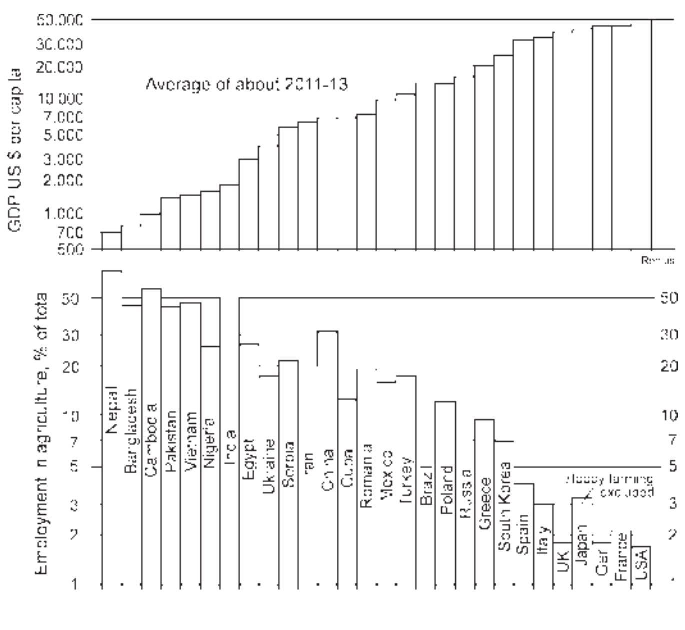


Figure 1 - GDP and employment in agriculture in % of the total number of working people [64] (GDP=Gross Domestic Product)
[Sources: FAO, World Bank, publications, Club of Bologna]

The important relationship between agricultural mechanization and national welfare can also be explained well by the so called *Three Sector Model,* as initially addressed by *Fischer* [17] and *Clark* [12] and directly after World War II also by *Fourastié* [19].
Some data from Fourastié (1963) have been extracted and drawn up in **Figure 2** for the US economy [60]. It indicates that in around 1820 more than 70% of the working population had been engaged in agriculture. Their number was reduced to "only" 10% in 1960 while the production (t/ha) also increased continuously.

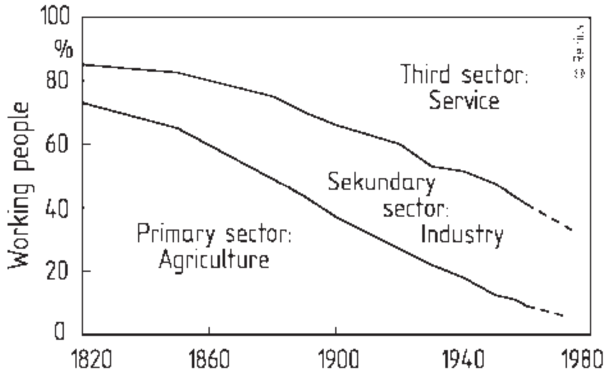


Figure 2 - Economy development of the United States by sectors [60]
[Source: 19]

Agricultural mechanization is therefore in almost all developing countries the key technology to overcome poverty, low expectation of life, high illiteracy, high infant mortality, low level of infrastructure etc. – summarizing this relationship means:

– a low level in agricultural engineering usually means a high level of poverty –

This underlines the mission of the *Club of Bologna*.
Regarding all machinery, the tractor was and is still the dominating piece of worldwide mechanization.

KEY AREAS FOR SUPPORTING TRACTOR TECHNOLOGIES WORLDWIDE – A SURVEY

The field of reasonable activities is widely spanned, as the general level of mechanization ranks from "very low" to "very highly sophisticated". Recommended actions for supporting developing countries – based on the experience of the author – are structured according to the following five groups (**Table 2**).

1. Tractor technology transfer by international publications and translations
2. Tractor technology transfer by international networking and co-operation
3. Tractor technology transfer by international standards and regulations
4. Strategies and methods for worldwide tractor developments
5. Producing, presenting or exchanging innovative ideas for future tractors

Table 2 - Supporting tractor developments worldwide: key areas

Some typical examples for the five items listed are outlined in the following paragraphs, in order to demonstrate priorities and relevant relationships with the *Club of Bologna*.

Tractor technology transfer by international publications and translations

Several scientific journals are available, but updated textbooks with design fundamentals on a scientific basis have been rare for agricultural machinery, including tractors. This raised the idea of the well-known "CIGR Handbook of Agricultural Engineering", covering all areas of agricultural engineering, written by more than 150 international experts, many of them members of the *Club of Bologna*.

Five volumes have been structured by Editor-in-Chief and *Club of Bologna* member Osamu Kitani (Japan) under the auspices of CIGR [34]. A 6th volume was added a little later, edited by *Club of Bologna* member Axel Munack (Germany) [39]. All six volumes have been edited and printed by the American Society of Agricultural Engineers (ASAE) in USA (since 2005 ASABE, American Society of Agricultural and Biological Engineers), which was greatly welcomed. Electronic versions are still valuable and available from ASABE.

An advertising text of a hand out:

> *"This handbook series is designed to help engineers and others involved in agricultural technology more effectively deal with the challenges of an increasing world population".*

Volume III "Plant Production Engineering" was edited by Bill A. Stout (USA) and Co-Editor Bernard Cheze (France) – both *Club of Bologna* Members [70]. In order to enlarge its technology transfer impact, it has been translated completely into Chinese in 2005 following a recommendation by the *Club of Bologna*, but organized by the Chinese Academy of Agricultural Mechanization Sciences (CAAMS) and the Chinese Society for Agricultural Machinery (CSAM).

Volume III contains agricultural tractors in three sections (original titles):

- Tractors: Two-Wheel Tractors for Wet Land Farming (J. Sakai, Japan) [65]
- Tractors: Two-Wheel Tractors for Dry Land Farming (A. Lara-Lopez, Mexico & W. J. Chancelor, USA) [36]
- Tractors: Two-axle Tractors (K. T. Renius, Germany) [57].

The Chinese versions have supported a now fast growing own tractor industry in China.

Tractor technology transfer by international networking and co-operation

Co-operations between industry and research institutions can support innovations and save time and costs and they have been addressed in several *Club of Bologna* studies, for example for tractors in 1996 [53].

The "Bajaj Tempo Tractor Project" can be cited as an example of a successful co-operation. The author was invited to join a management team of the Indian company "Bajaj Tempo" (now FORCE Motors) which had never before built tractors. There was almost nothing available within the company that was familiar with this business. However they had some experience in producing Diesel engines and simple transmissions.

The dream of CEO Abhay Firodia was to support the booming mechanization in India with a competitive product, produced 100% in the country and meeting both the local market demands and the very low price level. An adequate future orientated power train and a direct injection Diesel engine were the most important issues within this project. In order to reduce the risks, to save costs and development time, the tractor Diesel engine was developed on the basis of a license for the OM 616 car Diesel engine of Daimler-Benz (Germany) and the transmission on a license for the A-212 tractor transmission of ZF (Germany) (**Figure 3**). I was engaged in designing the overall tractor concept, to find the best fitting transmission concept (by license among a larger number worldwide), to define detailed lab test specifications for Indian conditions [52] and to train the staff in tractor technologies and modern test methods [50].

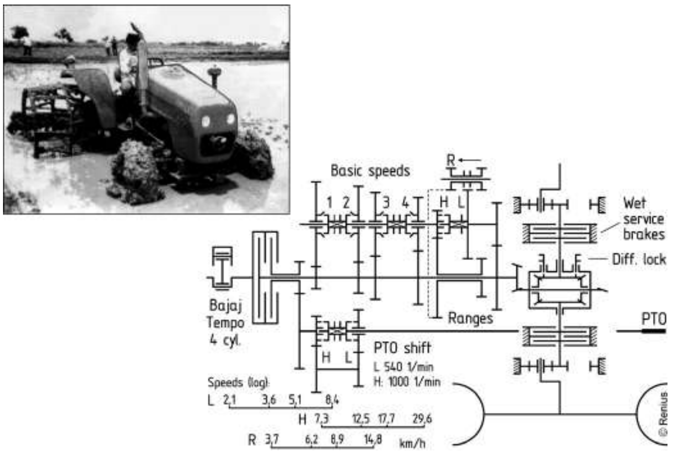


Figure 3 - The Bajaj Tempo (FORCE) tractor project (India): Transmission concept, based on a license of ZF transmission family A-212 with synchronized basic speeds 1-4. Tractor in paddy field operation (left), in series production since 1997 *[Tractor picture: courtesy FORCE, India]*

The tractor was put into mass production in 1997 and the concept is still competitive today without major design modifications. The CEO, Mr. Abhay Firodia, recognized this co-operation as a prototype for an outstandingly successful technology transfer and presented it (together with the two German consultants) to the *Club of Bologna* in 1999 [16]. The total Indian tractor production was able to grow dramatically over the past decades, the general mechanization progress was, however, moderate due to the agricultural structure [7]. The opposite occurred in China: The speed of agricultural mechanization is higher, reducing working people in agriculture as a percent of all workers, for example, from 50% in 2000 to 29.5% in 2014 [74]. Agricultural structure seems to be more in favour of mechanization and the government is pushing it by high subsidies. The author and other members of the *Club of Bologna* supported the Chinese tractor industry by several visits and seminars [6, 47, 54-57, 69].

Regarding industrialized countries, co-operation between research institutions and industry can create or support innovations, as outlined by *Club of Bologna* members for example in [53] and [10]. This is working very well in Germany and probably still has potential in other countries.

Tractor technology transfer by international standards and regulations

Standardization began thousands years ago, as outlined in a *Club of Bologna* review 2013 [23] (star observation and calendars in Mesopotamia, writing characters of the Sumer and Egyptians etc.), first coming to importance 2000 years ago under the Romans.

Standards and regulations have a very high economic impact. Regarding tractors they simplify not only the practical use – for example by standardized interfaces for implements – but at the same time also represent a comprehensive collection of design and procedure know how that is of special interest for developing countries. As an example, I can report that the working place configuration of the above mentioned Indian tractor was eval-

uated to be outstanding, although the design was "only" meeting the recommendations of ISO 4253.
Standards have initially been developed at national level (for tractors, for example, by ASAE in the US or UNI in Italy or DIN in Germany). Globalization has led towards worldwide ISO standards: The *International Standardization Organization* (ISO) started for tractors and agricultural machinery in 1952 and is now more important than national organizations. ISO subjects have been extended in the same time to new areas such as human relations, safety, emissions, communication systems, sustainability, recycling and others. Many national regulations and even homologation fundamentals now relate to ISO standards.
Regarding history, the American Society of Agricultural Engineers (ASAE, USA) has been a leader in tractor standards for a long time; see, for example, the first ASAE standard for the PTO from 1926.
Regarding the most recent development, six phases of standardization have been identified in [43] and later-on updated in a *Club of Bologna* meeting 2013 [2]:

- 1950s: reduction of design variety
- 1960s: interchange ability and usability
- 1970s: ergonomics & operator safety
- 1980s: tractor & implement interfaces
- 1990s: safety (CEN) & electronics (ISO)
- 2000s: systems and processes

Table 3 - Phases of standardization *[Source: 2]*

While technical aspects and customer demands had driven the first phases, standard methods for official regulations came up in addition – in particular addressing safety, environment and as a basis for tractor homologations and traffic regulations as well.
Some regulations and legal acts have been extremely successful in the developed countries, safeguarding human health or even saving lives, thus being a paradigm also for developing countries. Three very important examples may be listed:

- The introduction of *rollover protection structures (ROP's)* could reduce the number of fatalities in Germany by about 95% – similar in some other countries [61].
- The *noise reduction* at driver's ear within cabs could be reduced from about 100-105 dB(A) to now only 70-75 dB(A) – both for full power (OECD). The risk for hardness of hearing, which has before been a huge problem as it cannot be healed, could be convincing within the developed countries [61].
- The *"almost zero emission"* of Diesel engines of tractors and mobile machinery could be achieved in 2015 within the EU and USA, being a huge step towards environmental protection [13, 14].

All these regulations have been introduced first by governments as compulsory, but became step by step more or less popular as the farmers recognized the benefits. They all need clear definitions of the related test procedures. This has led to the philosophy of unloading the official regulations by procedures being standardized separately – if possible by ISO, as recently discussed in the *Club of Bologna* [1, 37].
The highest level in emission control has been achieved in Europe (EU) and USA – the latest status Tier 4 final (USA) is equivalent to EU stage 4 [13, 14] but is not yet very popular as many tractors now need AdBlue in addition to Diesel fuel.
Clean air acts are unloading the environment and there is no way back. The now introduced Tier 4 final needs however tremendous exhaust gas after-treatment installations (**Figure 4**). They can double the Diesel engine initial costs, increase the tractor initial costs by several percent and require AdBlue. This makes it under-

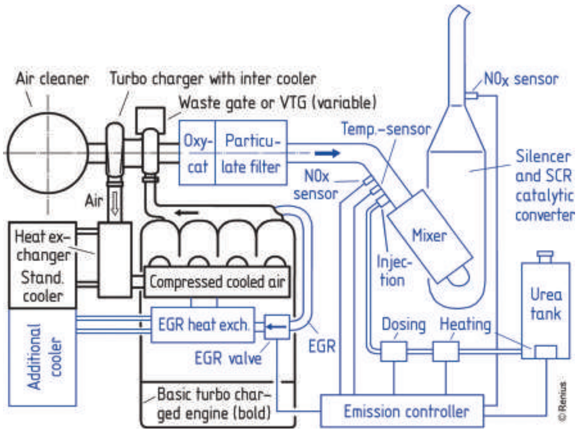


Figure 4 - Demonstration of the enormous technical amount of exhaust gas after treatment (blue) meeting EU stage IV and corresponding US EPA Tier-4 final for a 4-cylinder Diesel engine. Total costs are about doubled as compared with a simple Tier 2 Diesel engine (bold)

standable that the slogan "Diesel only" was popular for some years among farmers ahead of Tier 4.
Developing countries are usually behind this level but try hard to improve their environmental protection, as outlined for example in [32] for emissions and noise in India. I would like to add the need of ROP's (roll over protection structures), as their benefits justify in my opinion the low additional costs in all countries and have been accepted by the farmers in many developed countries.

Strategies and methods for worldwide tractor development

Global strategies regarding tractor specifications

Along with globalization, the agricultural machinery business has become more and more international. This resulted in new strategies of increased worldwide networking and co-operation, as for example already recommended in 1993 by Kitani [33] and confirmed in 1994 by Fischer (John Deere) [18] to the *Club of Bologna*. While Henry Ford could capture the world market with only one tractor model –his famous FORDSON F (1917-28) – today's numbers of tractor types are legion. The same applies to other agricultural machinery. The extremely wide span of demanded specifications and power levels cannot be covered by a few models.

Technology level	Nominal engine power (Low, Mediumk, High)	Wheel drive (Only 2-wheel drive, Front drive optional, 4-wheel drive stand.)	Diesel engine (1 Cyl., 2 Cyl., 3 Cyl., 4 Cyl., 6 Cyl.)	Drive transmission (Very simple, Simple, Partial power shift, Full power shift, Infinitely variable)	PTO (540/min -1, 540 & 1000/min, 3 or 4 Speeds)	Hydraulics (Rear 3-poit hitch, Remote Control, Rear and front hitch, Load Sensing hydr.)	Cab & ROPS (No cab, no ROPS, ROPS/low cost cab, Comfort cab)	Elec-tronics (Not existing, Low cosr concepts, High tech concepts)	Level of § (Low, Medium, High)	Typical merket regions
I	X	X	X X X	X	X	X	X	X	X	Africa
II	X X	X	X X X X	X	X	X X	X(X)	X (X)	X(X)	India
III	X (X)	(X) X	(X) X X X	X	(X) X	X X X	X X	X(X)	X(X)	EU, USA Japan
IV	X 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	X	X	

Table 4 - Worldwide demanded specifications for agricultural tractors, classified by five technology levels

Source: proposal 2002 with minor updating [58]

This was the reason to consider and finally present a rough classification of worldwide demanded specifications for tractors in 2002 [58] (**Table 4**).
Five levels have been settled, from "very simple (I)" to "highly sophisticated (IV, V)".
As it would be completely inefficient to develop a separate tractor family for every level, the challenge for product development is to cover all the five "technology levels" with a minimum number of components for a respective minimum number of working parts. This requires standardized platforms, components and interfaces and needs a long period of time and lots of discipline for a successful realization.
The dream of ideal product planning may be to realize a complete global tractor program using only one simple pool of common components and parts. But this is probably not realistic because of the wide range of local specifications, production skills, price levels and labour costs. The author thinks that at least two platform systems are necessary to be a basis for profitably developing tractors for all levels.
Cost benefits of platforms have been discussed in the Club of Bologna inclusive industry view, for example by Gavioli, CNH [24]. Further progress seems to be necessary, mainly regarding developing countries.

Management principles for worldwide tractor development
Agricultural tractors of the upper technology levels are now highly sophisticated technical systems and require adequate project management methods, with permanent control of *functions, costs and milestones*.
The first steps in product planning and communication for tractor development have been outlined by the author in a paper presented to the first meeting of the *Club of Bologna* in 1989 [49] (**Table 5**).
Its main message is that all four basic departments of a tractor company (sales also represent marketing) have to take over particular duties and that they all have to achieve a common agreement regarding the product specifications, the costs and the milestones. My personal experience from many cases is, that a larger project has no chance of realization even if only one department is not convinced of its success.

		R & D	Sales	Factory	Finance
Product	– philosophy, patents	●	●		
	– specifications	●	●		
	– general design	●	●		
	– components: make or buy	●	●	●	
	– estimated costs	●	●	●	
Market	– regions, areas		●		
	– restrictions, legal etc.	●	●		
	– market price forecast	●	●		
	– volume forecast		●		
Investment	– R & D	●			
	– factory			●	
	– service		●		
	– sales		●		
Capacity	– know how	●		●	
	– man power	●	●	●	●
	– buildings			●	
	– finance				●
Economic evaluation					●

Table 5 - Project foundation matrix. Black points indicate "action required"
[Source: 49]

Meanwhile, due to the complex development procedure of modern tractors, the time to market can be a problem. The principle of "simultaneous engineering" can save time, as also recommended in the 1989 paper [49] and later on also confirmed by Harms in his presentation to the Club in 2003 [28]. The core message is to do all the development steps and the

factory planning not consecutively, but to run them with a certain overlap in terms of the time scale. This saves time and money but puts additional loads on the project management.
A complete standard tractor line-up of the upper technology levels is usually formed by at least 4 tractor families (**Table 6**). Articulated 4WD tractors are not included – they form a separate family.
The basic objective is to limit the number of components and parts by using common parts within each family. The displacement per engine cylinder has now been more or less constant over three decades, at about 1.0 to 1.3 l, but the nominal power may have doubled in the same time, mainly by turbo charging with continuously increased air pressures and the introduction of inter cooling.

Tractor family	1	2	3	4
Rated power, kW (ISO)	45 - 75	80 - 120	120 - 180	200 - 300
Rated eng. speed, rpm	2000 - 2200			
Wheel base, mm	2300	2550	2800	3050
Diesel engine	3 cyl.	4 cyl.	6 cyl.	6 cyl. large
Volume of functions	moderate	very high		high
Comfort level	moderate	high	very high	

Table 6 - Product families (platforms) for standard tractors, possible configuration 2016 for upper technology levels III, IV and V

The ***specific costs per kW*** rated power are not unique for all the family members (**Figure 5**). The top model has the lowest costs per kW, as it usually offers the best performance utilisation of its components [72, 58, 31].

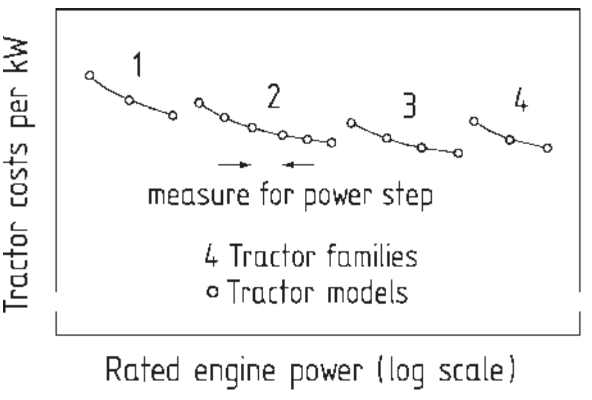


Figure 5 - Specific production costs of tractor models within a system of four families *[Source: 72, 58, 31]*

It should always be a strategic principle to *keep the curves flat* in order not to lose money with the smallest family model. This needs as many adjustments as possible without touching "high investment components" such as engine and transmission housings or sheet metal pieces. The logarithmic power scale has the advantage that ratios are always represented by distances, which represent the steps independent of the power level - which is much better.

Tractors of the upper technology levels are very complex technical systems – more sophisticated than most other types of vehicles (**Figure 6**). The power train with Diesel engine, gear box, PTO, final drive 4WD axles and the related electronics represents the heart of the tractor with more than 50% of total production costs.

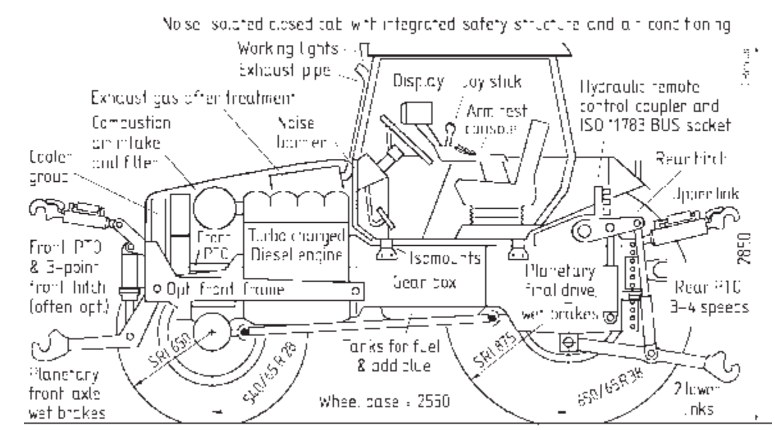


Figure 6 - Typical 4-cylinder standard tractor (family 2, 80-120 kW, technology levels IV and V). *[Source: Drawing by author, shape derived from typical components of several manufacturers]*

Producing, presenting or exchanging innovative ideas for future tractors

Innovative ideas are always welcomed for all the defined technology levels. Some principles for the lower levels have already been presented above.

The following content will discuss some fundamentals and trends for the upper technology levels.

The value of a tractor can be addressed by ten basic criteria (**Table 7**).

- Performance	- Down time risk
- Tractor functions	- Comfort and safety
- Fuel economy	- Styling and colour
- Dealer Quality	- Company image
- Reliability	- Resale price level

Table 7 - Criteria for evaluating agricultural tractors

Tractor-implement or tractor-trailer performance is mostly in the foreground regarding productivity, driving the trend to increased power. Larger tractors can, however, not only reduce production costs but also energy input per ha (or per km transport). Not so well known is the fact that the relative costs for maintenance and repair are decreasing with increased power levels, as the labour costs are always the same [21].

The total operational costs per hour for the farmer depend on the intensity of the tractor use. Regarding a 100 kW tractor, an annual use not below 800 h per year is recommended in order to minimize the influence of fix costs [21].

Tractor operation (field and road): performance, functions and fuel economy

Component properties	External mechanics	Process control
- Diesel engine	- Tractor weight	- Driver information
- Transmission	- Implement & trailer forces	- Internal BUS
- Axles, 4WD, tires	- Ballast weights	- External BUS
- PTO concept	- Axle load distribution	- Assistance systems
- Hydraulics	- Terrain characteristics	- Automation

Table 8 - Factors affecting tractor-implement performance and fuel consumption

Table 8 displays a survey on the factors affecting tractor performance and fuel consumption. This will be discussed in the following sub paragraphs.

Component properties

Diesel engines have been developed for increased power but decreased emissions, keeping the low level of their specific fuel consumption at values of about 200 g per kWh net (including fan drive). High power densities of four-cylinder engines had not been popular for a long time (in favour of moderate turbo charged six-cylinders), but could now come up to high effective cylinder pressures, even up to about 2 MPa (20 bar).
Tractor transmissions are offered in a broad worldwide variety, from very simple to very sophisticated. A classification by technology levels, as demonstrated for the whole tractor, is also useful for transmissions (**Table 9)** [63]. Continuously variable transmissions (CVT's) represent the highest technical level, offering stepless automatic modes [59] – including electronic Diesel engine control. CVT's compete with full power shift transmissions which have also reached a very high level of automation and comfort.
An efficiency target for CVT's as published 1994 by the author for large tractors [51] became a general basis. Although its level is little below that of well-designed power shift transmissions, measurements by the German DLG test station could demonstrate that there is no difference [35]. The reason may be that CVT's allow a more refined adjustment due to the stepless control.

Technology-levels	Speeds, km/h forward	Speeds, km/h rev.	No. of speeds forw	No. of speeds rev.	Type of shift	PTO rpm's	Final drive	service brakes	Lubrication	IT-level	Typical markets
I	2–25 (30)	3–8	3–8	2	Slid, Coll	540	bull gear & planetary	dry & wet	by splash	no electronics	Developing countries,
II	2,2–30 (32)	3–10	8–12	4	Coll, Syn	540 (1000)		wet disc brakes			India, China, South Am
III	(0,5) 2,4 – 30 (40)	3–15	12–16	4–8	Syn, Hi-Lo Syn shuttle	540, 1000 plus opt. eco-speeds	planetary		by oil pump + filter	low	South and East Europe
IV	(0,3) 2,5 – 50 (60)	2–30	16–32 (64)	16	Syn, Part. PS Power shuttle					high	Premuim markets
V	2,5–50 (60)	3–30	19–23	6–12	Full PS, autom.					very high	
V	0–50 (60)	0–30	Infinitely		CVT, autom.						

Slid = sliding gear, Coll = collar shift, Syn = synchroshift, H-Lo = Hi-Lo power shift, Syn shuttle = Synchronizd reverser, Part. PS = part. power shift, Power shuttle = power shifted reverser, Full PS = full power shift, CVT = continuously variable transmission, autom. = automatic shift

Table 9 - Structuring worldwide demanded transmission specifications by technology levels *[Source: 63]*

The very broad variety of tractor transmissions can be demonstrated by two examples in production. An Indian transmission (level II), based on a ZF license, has already been shown in **Figure 3**.
A similar, but new development by Carraro represents a transmission family, addressing levels I, II and the lower end of III with a very flexible structure (**Figure 7**). The basic 8-speed section needs only five pairs of gear wheels (as originally realized in transmissions of Deutz and Ford [63] 50 years ago). This saves costs, although with a few restrictions in setting the nominal speeds as compared with the ZF solution.
This Carraro transmission family offers many options to cover both level I and II. Upgrading options are for example synchronized basic speeds, synchronized shuttle, synchronized Hi-Lo splitter, two-speed PTO, planetary axles, wet brakes etc.

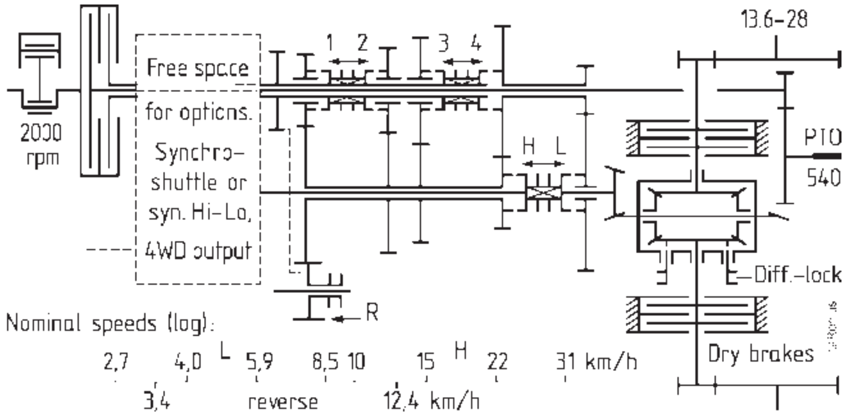


Figure 7 - Carraro transmission family, developed for the Indian market, version T3-0 basic, (since 2011), technology level I, nominal input power up to 25 kW
[Source: 63; information courtesy Carraro]

Coming to the upper end of the level scale, Fendt has presented its second CVT generation VarioDrive (**Figure 8**). It has advanced from the first Vario concept (1996) but now with two merger shafts on which the two hydrostatic motors act. The energy efficient "multi-motor" principle allows only one single range from full reverse to full forward (60 km/h) [35].

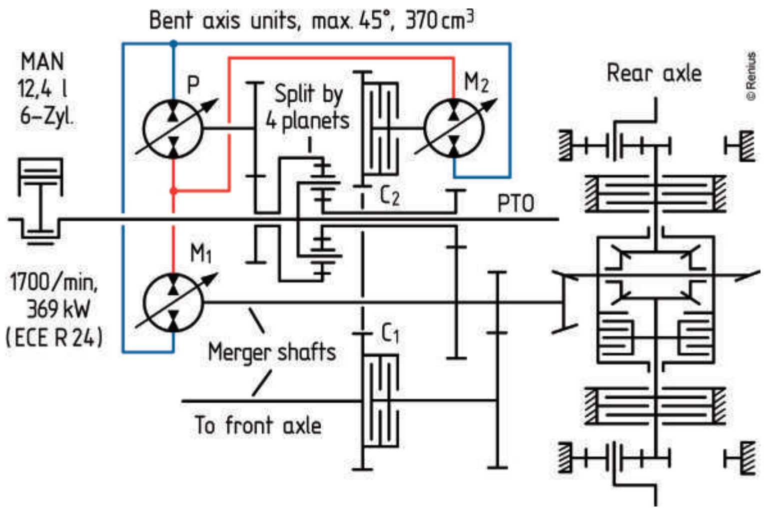


Figure 8 - Second generation of the Fendt Vario CVT, now called "VarioDrive" with only one range and new four-wheel drive functions (2015)
Source: 3; information courtesy AGCO-Fendt]

This transmission also offers a new 4WD function: In a normal off-road operation straight ahead clutches C1 and C2 are closed, while the two hydro motors M1 and M2 are operated in parallel, as in the first Vario. In this mode there is a fixed speed ratio between the tractor axle drives, as usual until now for almost all standard tractors when driving straight ahead. However, this fixed axle ratio is very unfavourable for cornering or driving at higher speeds on the road. For this reason the standard method until now was to deactivate the front drive automatically in these situations. This has been recognized for many years to be unsatisfactory, and was the reason to look for innovative ideas. A first solution for the "pull-in-turn problem" came from Kubota 1986, named "Double Speed Turn". It was, and still is, to use an automatic front axle overdrive (1 step) for sharp turns and was becoming popular in Japan, but not in Europe due to several reasons.

Innovative four-wheel drives have been proposed for several years with many patents. The new Fendt VarioDrive is now solving the above mentioned problem using a continuously working structure. This innovation has an interesting research history, underlining the strategic benefits of a well working co-operation between universities and the related tractor industry.

Research at TU Munich has been carried out under the author since 1986 to look for a European solution for the mentioned problem. Two publications [11, 26], based on dissertations, resulted in a prototype with infinite adjustment of the front axle input speed relative to the rear axle speed. A prototype system was applied to a Fendt tractor and was working very well. The author of the second thesis (completed in 2002) became several years later manager of the AGCO-Fendt transmission department and his team was working under his guidance again on a series solution based on the Vario. The result could now be presented with the new generation "VarioDrive" for the very large Fendt 1000 line [25]. A hydrostatic longitudinal differential function by opening the clutch C1 provides permanent non-distorted all-wheel drive. Torque distribution is infinitely controlled by displacement of the hydro motors. In addition, the differential effect can be overridden by clutch C1.

Axles have generally been equipped with improved brakes. Wet concepts are very popular as they can be designed "life time" and completely closed (even for paddy fields). Idling losses at higher speeds could be reduced, but are still a certain handicap for regions such as Europe. ABS technologies are becoming common for larger tractors, perhaps in the future compulsory within EU for higher speeds. It seems that the use of pneumatic ABS truck systems has some advantages against hydraulic systems, as the components are more or less available.

Limits of tractor growth. Tire sizes increased over the years over proportion. This has however a clear physical reason, as forecasted decades ago by terramechanic scientists – for example by Söhne [68]. Practical consequences have been outlined in 1987 by the author at the UNACOMA Symposio Internationale (which was of major impact for founding the *Club of Bologna*) [48].

The phenomena behind it had already been addressed by Galileo Galilei 1638 in his "Discorsi" [22]. He observed that enlarging all elements of a system with the same geometrical factor λ can lead to overloads of supporting elements.

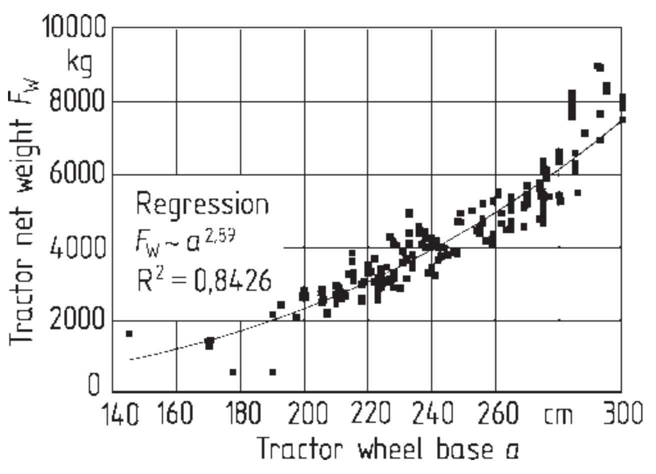


Figure 9 - Tractor weight versus wheel base *[Source: 44]*

This can be explained by a simple law of similarity. Addressing the limits of tractor growth, the main point is that the tractor weight increases with a theoretical exponent 3 of the enlarging factor λ if the same materials are used. Research at TU Munich could demonstrate that the practical exponent is very near to 3 if the tractor net weight is plotted versus the wheel base, being a typical measure of geometrical size (**Figure 9**) [44]. If all tire dimensions are also enlarged by the factor λ their footprint areas will increase only quadratic resulting in a higher soil pressure and compaction.

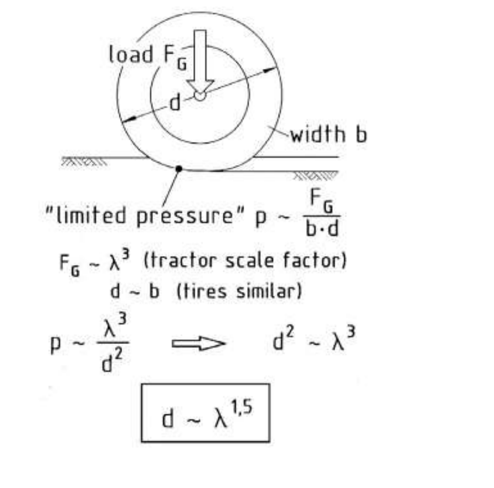


Figure 10 - Tractor growth limits due to ground pressure. Increased tractor size by factor λ needs an in-creased tire size by factor $\lambda^{1,5}$ *[Source: 48]*

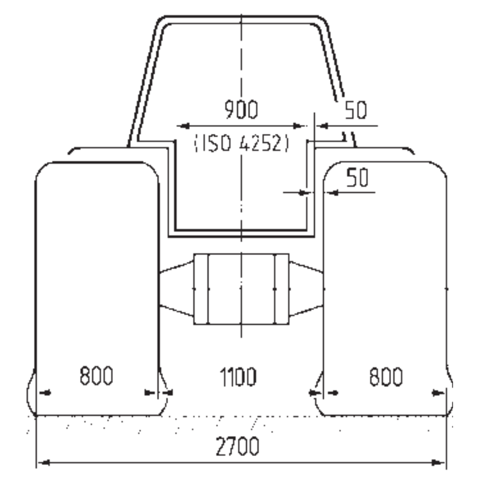


Figure 11 - Influence of cab and tire dimensions on the tractor width (small tractors with track width £ 1150 mm excluded)

The footprint area is usually proportional to the tire projection (d x b) (**Figure 10**). This means that the contact pressure is proportional to the load divided by the tire projection b x d and thus will increase with the enlargement factor λ. As this is not acceptable (to protect the soil against compaction), the tire dimensions must be enlarged not only by factor λ but by factor $\lambda^{1,5}$, as demonstrated in Figure 10.

Regarding the practical development the tires have increased much more in width than in diameter, as this is more cost effective regarding both the tire costs and the transmission final drive costs. But this trend has limits as outlined below.

Tractor width limits. The ISO standard 4252 requires a minimum inner clearance of 900 mm for cabs of standard tractors with at least 1150 track width (**Figure 11**). This is, for example, a must to obtain EU homologation.

Assuming a wall thickness of 50 mm, a horizontal tire clearance of 50 mm and 800 mm width of large low section tires, the outside tractor width arrives at about 2700 mm. This is already approaching limits for public traffic in several countries. Duals are usually not possible on-road in many countries, as they lead to an even higher width.

This situation is setting growth limits, mainly in countries with tractor use on public roads. Some alternatives may be discussed. *Full tracks* could gain certain popularity, with the well-known concept of Caterpillar since the first "Challenger 65" from 1987. Track units have meanwhile also been applied to articulated 4WD tractors and could be a future trend also for standard tractors (**Figure 12**).

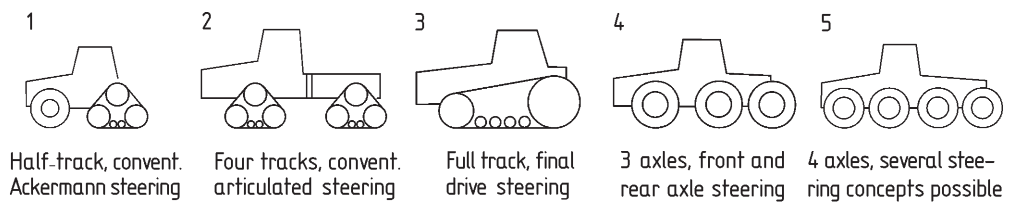


Figure 12 - Five alternative ground drive concepts for high-power tractors improving pull forces, energy efficiency, soil conservation – all for a limited tractor width

Full tracks require a high technical amount for the power steering, integrated in the final drive. The replacement of tires by *half-tracks* (versions 1 and 2) can keep the steering system simple.

Solutions with *more than two axles* and tires such as the Fendt study prototype TRISIX [41] (4) or a Deutz-Fahr prototype (5) offer the best abilities for on-road operation including high speeds.

Mechanical PTO concepts of the upper technology levels offer at least two standard speeds of 540 and 1000/min, often completed by one or two optional eco-speeds for saving fuel, by achieving the standard speeds at reduced engine speeds. The engagement is mostly done by multiple disc clutches in the rear, with automatic control enabling a life shaft for auxiliary drives. Front PTO's are popular in Europe. Recommended maximum PTO power has been increased over the years by ISO 500 for all "types 1, 2, 3" adding a "type 4" with 1300/min nominal speed and even larger diameter for very large tractors.

CVT-PTO's have been proposed with prototypes to improve productivity and comfort but could not gain importance until now. Same for power shifted PTO speeds. Studies at TU Munich showed that the limited space hampers the introduction of higher technologies and that economical chances for a power shifted PTO may be higher than for a CVT-PTO. Important criteria are: initial costs, efficiency, space, safety and comfort. Efficiency is not only important for practical use, but also a marketing factor in countries where the tractor price is derived from its nominal PTO power.

Conventional PTO safety arrangements are recommended by ISO 500 regarding combination of the selected PTO speed with the relevant standardized shaft profiles. This is mainly an issue when shifting up to higher PTO speeds without changing the shaft profile.

Electrical PTO concepts can offer advantages by direct power transfer from tractor to implements, while the energy losses of the transfer wire are much lower than with the tractor hydraulics. A first factory-installed integrated electric generator was presented by John Deere 2007 and entered production from 2008 for 7030E models. A 20 kW generator was supplying 480 V three phase AC current for engine auxiliary components and 5 kW for tractor implements [62]. The initial success was limited, but the trend is going on.

Today, larger generators are offered by several component suppliers – often driven by the conventional front PTO. Interesting benefits have been reported, for example when combining the generator with an electric auxiliary axle drive of a large slurry tanker [27]. Two key points can be identified as comparing the better energy

balance with a pulling 4WD tractor: the rolling resistance of the tanker is compensated directly (not via the moderate tractive efficiency of the 4WD tractor) and the electric power train has a higher efficiency than a hydraulic one. The energy saving effect, together with a certain additional pull of the trailer, increases both productivity and fuel efficiency.
A hydraulic power transfer would be less energy effective, but would still be superior to the conventional case of only pulling the tanker by a 4WD tractor.

External mechanics

External mechanics influence *tractor performance and fuel economy* by two groups of parameters:

- vertical forces on the drive system
- terrain and soil conditions

The rule "a tractor should be heavy for good traction" is a *popular error* because of three reasons:

- High initial costs
- No possibility for "low weight operations"
- Low pay loads

Pay loads are a strong demand mainly for mounted implements. The market requires values of at least about 60% of the net tractor weight while the best tractors approach values near 100%. If the net weight is too high for a certain operation, a reduction is not possible. A low tractor weight is – for example – required for PTO operations or for pulling operations at higher speeds.

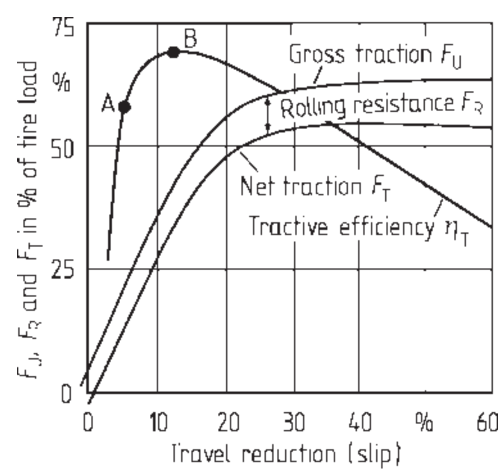


Figure 13 - Forces and efficiency of a pulling tire on dry stubble. A - tire load too high, B - tire load reduced

The rule "to get down the slip as much as possible" can be wrong in case of low slip values (**Figure 13**) [46].
Tractive efficiency has an optimum at a certain slip value, for traction wheels often between 8 and 14%. Point A indicates for example poor tractive efficiency although the slip is very low. The explanation is a relatively high rolling resistance. Reducing the tire load (for example by taking ballast away) leads to point B achieving both a higher pull and lower fuel consumption.
Regarding the productivity maximum, this again needs higher slip values, while fuel efficiency is now decreasing. It is recommended for wheel systems to look for a compromise – for example with net traction ratios (pull force/vertical force) between 0.30 and 0.45 [75]. As the tractor driver is overburdened to control such traction mechanics by observation, driver assistance systems have been developed [42] – for example with the following two limiting strategies: *Optimized fuel economy* and *maximized productivity.*

Practical operations are often in between both. Tire inflation pressure control has been proved to be an additional and very effective parameter for making the whole pulling process more energy efficient - with additional benefits for soil protection. This was known for decades, but seldom properly used. However, traction tires offer an unusually wide band width of specified inflation pressures, so that low pressures can be used off-road and high pressures on-road. As a lower speed allows a higher specified load, the off-road inflation reduction must not result in load restrictions. Research has been carried out at TU Munich under the author [45] and a lot of practical demonstrations have been made under Prof L. Volk at "Fachhochschule Südwestfalen (Soest)". Fendt has for some years been offering a factory-installed system and there is probably huge potential for a broader general introduction.
Limits for contact pressures have been discussed for several decades and even became the subject of political debates addressing soil protection. Practical values have been worked out for modern agriculture in Western Europe by VDI guideline 6101 including large machinery [71].

Process control

This third column of Table 8 has dramatically gained importance within recent decades, mainly by introducing electronics and closed loop controls (**Figure 14**). The "cybernetic principle" was early addressed by Maxwell 1867 [38] as outlined by Isidori [30] at a recent *Club of Bologna* meeting. The actual output value of a process is all the time measured and fed back, to be compared with the target (set value). Deviations are corrected by the regulator compensating disturbing factors.

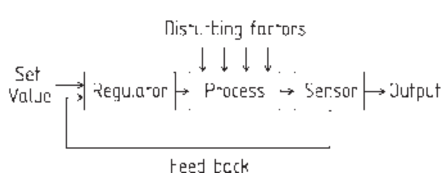


Figure 14 - Closed loop control as a key technology for automation in agriculture

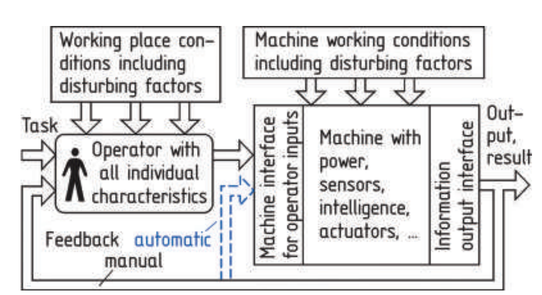
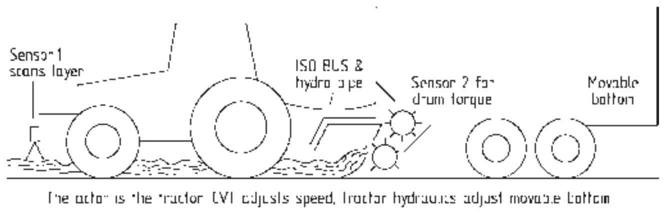


Figure 15 - Unloading the driver by automatic regulation and correction for upper tech levels by digital electronics *[Source: [57]*

The tractor driver was for a long time part of such a closed loop control, comparing for example the position of wheels related to a plant row with a target (mid of plant row) and acting in the sense of adjustment (steering). Automatic modes allow for unloading the driver and improving the process (**Figure 15**). The blue feedback bypasses the driver, automatically comparing the feedback with the target and carrying out permanent automatic correction [57].
Automatic closed loop controls are applied on both the complete inner technical structure of modern tractors and the combination with implements. Even complete machinery systems are controlled to realize the so called "precision agriculture". This megatrend of agricultural mechanization has been early recognized by the *Club of Bologna* and supported in several meetings.

This type of control is usually more productive than a human manual control. It saves energy, can better protect the environment and offers – in addition – a higher comfort level.
A very first example regarding tractors shall be mentioned: the invention of the three-point hitch draft control for mounted implements by Harry Ferguson [30] – represented by his British "master patent" No. 253.566 from 1925. The principle is still used today for the majority of worldwide produced agricultural tractors.
Early German research on BUS systems of Auernhammer [3] resulted in a national standard on digital tractor-implement communication later becoming a basis for developing the world standard ISO 11783. This "ISOBUS" initiated broad activities in the developed countries [4, 5, 8, 20, 29, 66, 67]. Building up closed loop cycles using this standard was – for example – subject of a dissertation at TUM (under the author) with the title "implement controls tractor" [20], now replaced by the more general term "TIM – Tractor-Implement-Management".
An early application of the ISO 11783 system for a tractor-implement combination was published by John Deere in 2009 for a self-loading wagon of Pöttinger (**Figure 16**). The sensor 1 is scanning the grass layer in front of the tractor to get information about the profile and thus the expected mass flow. A second sensor is picking up the drum torque at the wagon input and can adjust the tractor speed in order to prevent over loads and under loads – finally, to use the full potential of the loading process (often combined with a cutting process), the bottom of the wagon can also be moved automatically, giving signals via the ISOBUS to the load sensing hydraulics of the tractor.

Figure 16 - "Implement controls tractor" automatically by its CVT transmission and LS hydraulics
[Source: Graphics by the author, information courtesy John Deere and Pöttinger 2009]



Several other applications have been presented in the meantime, for example a tractor speed control by a baler checking the mass flow by forces or torques. Another example is the transfer of the tractor control to the combine driver during overloading grain to a pulled wagon (**Figure 17**).

Figure 17 - Example of TIM – tractor-implement management: the driver of the combine controls the tractor motion during conveying the grain into the wagon. Increased productivity by saving time deleting any interruption and perfectly using the wagon capacity
[Source: courtesy CNH]

Regarding the higher technology levels, the driver has access to the digital electronic system through his terminal inside the cab. The monitor and the most important control elements are often fixed at the right hand armrest of the seat, moving up and down together with the driver to give a high level of comfort and precise fingertip control (**Figure 18**).

Figure 18 - Terminal, Joystick and the most used control elements combined on the right hand seat arm rest moving together with the driver
[Source: courtesy John Deere]

The strong technical trend towards automation is typical for the upper technology levels. It enables modern "precision agriculture", based on:

- The enormous *general progress in digital IT technologies* (functions, costs, availability, reliability).
- New *IT-friendly components* with interfaces for digital CAN BUS control and information systems.
- The use of now almost all information channels for optimizing agricultural processes

A vision of completely integrated IT technologies in agriculture was already demonstrated in 1995 by Club of Bologna members Auernhammer and Schueller, for example documented in 1999 in the CIGR Handbook Vol. III [6] on page 599 (**Figure 19**).

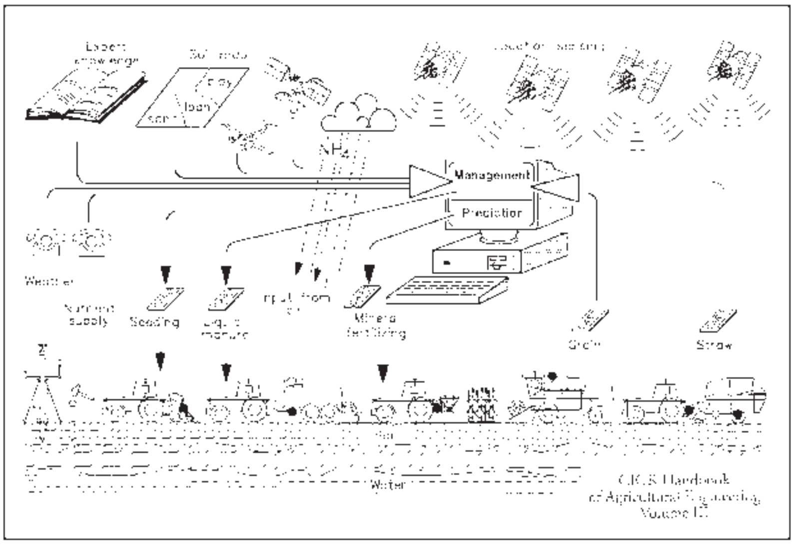


Figure 19 - Integrated farming system with IT penetration, vision of Auernhammer and Schueller
[Source:34]

This has meanwhile taken place and is still ongoing - right now for example by integrating the performance of smart phones and cloud computing in the whole machinery and farm management system.
Because of this megatrend in agriculture and agricultural mechanization, the well-known CIGR Handbook, Volume I to V [34] was completed in 2006 by Volume VI [39] offering a comprehensive survey on all important aspects of information technology in agriculture.
The huge IT penetration in all areas of agricultural engineering offers basic holistic benefits (**Table 10**).

- Productivity	- Environment protection
- Prrocess quality	- Energy efficiency / CO_2 reduction
- Product quality	- Safety and comfort
- Traceability	- Farm management

Table 10 - Benefits of IT penetration in agricultural engineering with particular reference to tractor technologies

Regarding the ***distant future***, fuel cells are discussed for the power train, some first introductions for cars are taking place in Japan. Fuel cells have little higher efficiencies than Diesel engines – however with the advantage that they deliver electric energy directly. In case of using hydrogen they offer zero emissions as demonstrated by CNH by a prototype presented at SIMA 2009) (**Figure 20**).

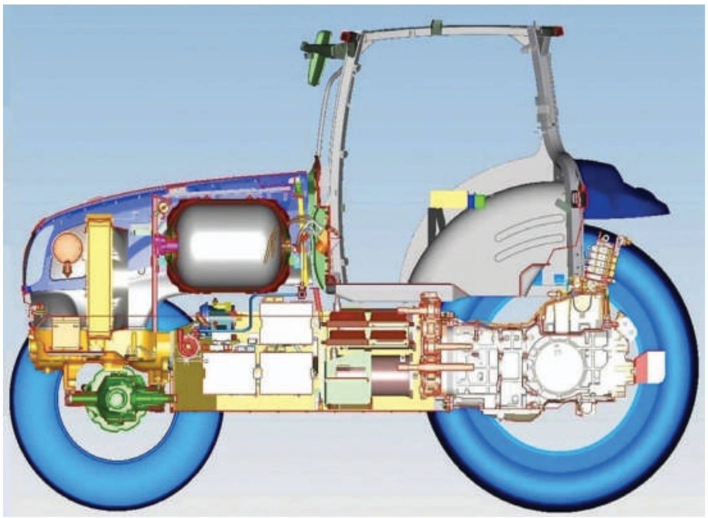


Figure 20 - Agricultural tractor with hydrogen fuel cell, CNH prototype SIMA 2009
[courtesy CNH]

One basic problem is the hydrogen storage: Tanks for pressurized hydrogen are too large for one day of operation, liquid hydrogen is difficult to handle. Special fluids binding nitrogen or fuel cells burning other liquid fuels than hydrogen are under research.
Other potential alternatives for future tractor drive lines are discussed recently in [63]. Diesel-electric tractor CVT concepts offer little lower fuel efficiencies than well designed hydro-mechanical power split transmissions. Battery driven concepts may become interesting for tractors with low average power use, but would again need higher battery power densities and lower battery costs.

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CHAPTER 3

AGRICULTURAL MECHANIZATION IN EUROPE

CHAPTER 3 AGRICULTURAL MECHANIZATION IN EUROPE

BY **PETER SCHULZE-LAMMERS** (GERMANY), **MILAN MARTINOV** (SERBIA),
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SOCIAL AND ECONOMIC EVOLUTION OF AGRICULTURE

Agriculture covers 47% of the EU territory and has a strong environmental impact. Farmers use soil, water and air, and it affects these resources and biodiversity, through land management practices, input use, cropping and livestock patterns. Agriculture is an important economic sector in Europe with a turnover of 211.9 billion € in 2015 (crop production).

A major change in agriculture within the European Union happened with the extension of the EU to 28 member states. The inclusion of Central and Eastern European Countries (CEEC) increased the importance of agriculture on the entire economy. Gross Domestic Product of CEECs was 6.6% as compared to EU 15 with only 2% in 2001. The employment in agriculture in CEECs was 16% with of EU 15 2.0%. The area utilized by agriculture rose by an additional 30 million ha from 130 million ha (EU 15) when including CEECs [54].

Agriculture accounts for roughly 40% of the EU budget. It is the only policy almost entirely funded from the EU budget, where European spending is largely complementary to national spending. In the 1980s up to 70% of the EU budget was allotted to agriculture. With the commitment to reduce domestic support and import duties on agricultural products as well as export subsidies, the European agricultural policy of market and price support turned towards direct income support in the main part. The support prices for cereals and beef were progressively reduced by up to 33% and "set aside" was used to reduce over-production. AS compensation farmers received "direct payments". Other actions such as extensification, afforestation and early retirement have also been introduced as policies by the EU. Eventually to a greater extent environmental concerns were introduced in the ***Common Agricultural Policy (CAP)***. In recent years the CAP is a major topic of European policy. The CAP has always had an impact on the transformation of living conditions in rural Europe. Globalization, climate change and strengthening of rural areas will continue to shape the future profile of the CAP. In 2003 agricultural reforms by the European Union began to decouple direct payments from production. To receive direct payments in full farmers, under the so-called "cross-compliance", must meet numerous legal obligations regarding the environment, animal and plant protection, animal health, soil and water conservation as well as food safety and maintenance of arable land in a good agricultural and environmental condition. Moreover, the direct payments, also known as Pillar I, have been reduced, and member states are able to use programs under so-called "modulation" to use Pillar II and national funds for environmental, rural development and similar issues [30].

Eurostat estimates agricultural crop production and animal production as 161.5 billion € in EU 28 for 2015. 13.7 million farms existed in 2007 in the EU 28, and the countries with highest farm numbers were Poland 3.9 million, Romania 2.30 million, and 1.68 million in Italy. 7.15 million farms grow cereals, indicating that grain is the most important crop in Europe.

The EU covers an agricultural area of 186.355 million ha, out of which 9.9% is land equipped with irrigation, which is 46% of the area in agricultural use of the United States of America [20].

Utilized farm area is 175.815 million ha, of which 44.5% is cultivated for common wheat. **Figure 1** outlines the map of EU 28 in 2010 for utilized agricultural area as a percentage of total area. The Benelux states, together with United Kingdom and Denmark, use more than 60% of their national areas for agriculture, indicating a high level of farming intensity. Less than 20% of the total area is under agricultural use in Sweden, Norway and Finland.

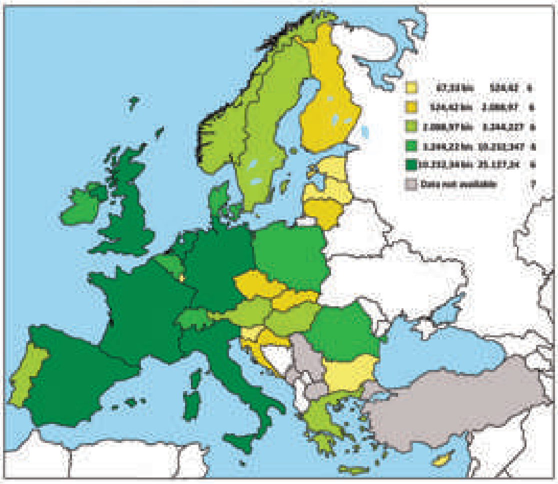

Figure 1 - Utilized agricultural area in percentage of total area, 2010 EU28 *[Source: Eurostat 2015 © European Union]*

Organic farming has become an important agricultural sector in Europe. EU 28 had 10.315 million ha of organic crop area, including Spain with the largest proportion at 1.710 million ha and Italy with 1.387 million ha.

Biomass as a renewable energy source has gained increasing importance in the past two decades. The production of biofuels reclaims a reasonable share of the arable land to grow vegetable oil crops and cereals or sugar beet for ethanol production. Almost all EU-countries introduced biofuels as a blend of the regular fuels. Production of biofuels accounts for blending rates between 3.5% and 7% for ethanol and is in the same range for biodiesel.

The annual working hours of farm work dropped between 1990 (EU 12) and 2015 on average by more than 43.5%. Farming employs approx. 20 million people in the EU, many of whom are in rural and peripheral regions where there are few alternative employment prospects [30].

Agriculture is an active factor in causing ***climate change*** as well as being passively affected. The predicted consequences are expected from precipitation, which has become greater in some countries with unfavorable distribution and heavy rain and storms. The prognoses of the expected temperature increase have positive and negative influences on agricultural production depending on the location [20, 29].

Agriculture provides for ***human nutrition*** and must be aligned with dietary habits. In Germany 80% of consumers are satisfied with the quality of food products from the German agricultural and food industries. At the same time, representatives of the food production sector (83%) and farmers enjoy (80%) large consumer confidence.

Agricultural production in EU 28 for 2015 accounts for 210.207 million € for crop products and 158.308 million € for animal products. A high level of production is in the central European countries (France, Germany, Italy, Spain and The Netherlands). The numbers indicate that 75% of the income of the EU farmers originates from plant production, but animal production remains in regions with high consumption of meat and dairy products.

Special attention is on the application of ***pesticides***. EC-regulation 1107/2009 from Oct 2009 concerns the marketing of plant protection products and regulates the testing and approval of pesticides and their active ingredients, as well as other issues such as parallel imports, controls or record-keeping. This includes a commitment by the member states, to adopt national action plans on the sustainable use of pesticides, and mechanisms for expertise or for testing of plant protection equipment. The general principles of integrated pest management came into effect from 2014. In recent years the use of glyphosate in agriculture as a total herbicide has been questioned because of its frequent use in agriculture and residues in food. It is expected that the use of synthetic pesticides in the EU will become more regulated and farming will have to consider other practices for weed and pest management. Because of these reasons many research activities in the field of mechanical weeding and recognition of pests by technical sensors are taking place. The Club of Bologna (2009) under the topic of "Innovations for Sustainable Agricultural Mechanization" intensively pointed out the importance of advancements in pesticide application technology, stating that the use of sensors as well as GPS and GIS contributed to the efficient application of pesticides, enhancing the value of field crops.

DEVELOPMENT AND ROLE OF MECHANIZATION

"The evolution of European agriculture and of its mechanization depends on a plurality of elements, external and internal to this production system" [23]. The increase in GDP, the new role of developing countries, the evolution of trade exchange and a strong demand for raw materials are listed as external factors. Among the internal factors there is a trend to offer an increasing variety of agricultural products as well as a growing demand for food products from developing countries. The author likes to add that a condition for the successful evolution of mechanization in Europe is a strong and innovative agricultural machinery industry based on an advanced professional and scientific education of staff. Moreover the role of standardization has a special significance for the agricultural machinery sector. The EU published in 1974 the first directive on tractors and the European Committee for Standardization (CEN) now has 33 members setting up new standards as well as updating existing standards. The special significance of standardization was exhibited at the Club of Bologna meeting in 2013 and was involved with the interchangeability between tractors, implements and other agricultural machinery, with a focus on the safety of these machines and with regard to their environmentally-friendly use. Standards are to satisfy the stakeholders` needs, which are on the one hand reliable and safe machinery for use by farmers and on the other hand the harmonization of market conditions e.g. uniform legislative requirements which ease the sales of machinery for the manufacturers [1, 22].
The evolution of the agricultural machinery market and production in Europe is represented in the next chapter.

Market and production of agricultural machines in Europe

In 1991 the Western European market for agricultural machinery declined by 11% as compared to the previous year. GATT talks and EC-politics caused restraint from investing in agricultural machinery amongst farmers [65]. This trend kept on to 1993 and the first recovery of the market commenced in 1994. The appearance of BSE caused the British market to decline in 1995 and 1996 significantly, but the rest of European farmers invested continuously in more agricultural machinery. From 1998 to 2004 the Western European market declined again and was followed by an upswing from 2004 with an exceptional year in the financial crash of 2008. The production volume in the EU amounted to 27.2 billion € in that year. Increasing demand for meat and intensification of agriculture are given as the main reasons for this trend [63]. In 2009 and 2010 a significant reduction in sales occurred, due to an economic depression in the previous years. Volatile markets and revision of laws at a European level affected the motivation for farmers' investments to high extent [38]. In the first decade of the 21th century the market for agricultural machinery in Europe was affected by the extension of the European Union to the Eastern European states, and accounted again for a peak value of 29.3 billion € in 2013. Most important markets are in Germany and France, followed by UK and Italy. In nearly all Eastern European countries the market grew in the last decade, even though in some years there was a temporary decline.

In recent years the EU-market was between 21.4 and 29.3 billion €, which is the highest fraction of the world market so far (**Figure 2**). The figure outlines as well that NAFTA-sales are almost equivalent and that Chinese industries have developed their sales in the last ten years successfully.

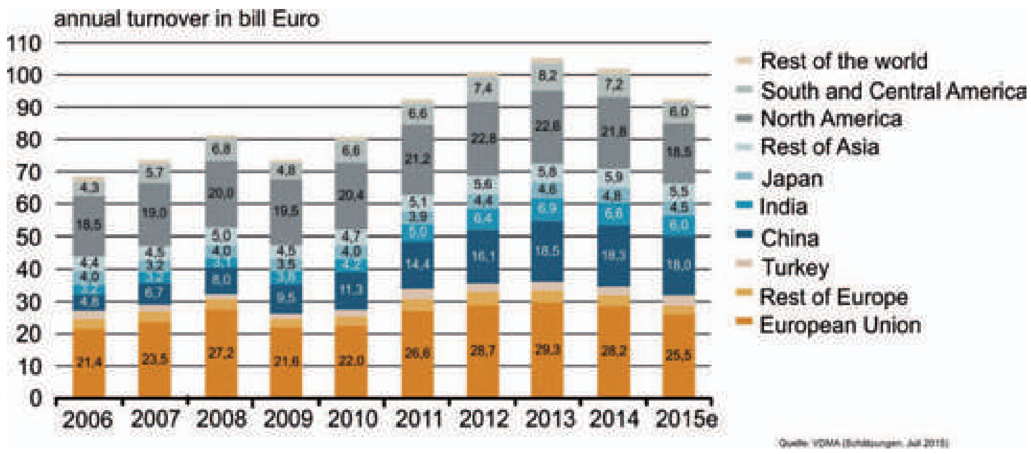

Figure 2 - World market for agricultural machinery, including EU28 in figures € *[Source: VDMA]*

The mechanization in live-stock farming is primarily marked by products having medium and long-term product life cycles. Livestock buildings and facilities for feedstuffs and residue storage are used for decades.

Tillage

The primary tillage operations of ploughing and deep tillage are traditionally followed by lighter secondary tillage operations. The aim of any primary or secondary tillage technique is to produce suitable seed and root beds for optimal yield with the minimum of necessary inputs of labour, fuel and machine use. Other physical, biological and chemical constraints to crop growth must also be considered to a greater or lesser degree;

- Timeliness and availability of labour and machines;

- soil conditions caused mainly by the weather;
- soil conservation by allowing good infiltration, or holding of water to reduce run-off and erosion;
- soil compaction must be minimised to enable good root penetration for moisture and nutrients during the growing season;
- weed control by mechanical disturbance and burying;
- soil size, or clod, reduction to provide good seed bed, germination and high emergence, and
- crop residue incorporation is often required.

To achieve these outputs tillage implements use mechanical manipulation of the soil through cutting, inverting, lifting, shattering and mixing; often several actions are combined.

Developments over the last 25 years

Conventional tillage systems and implements

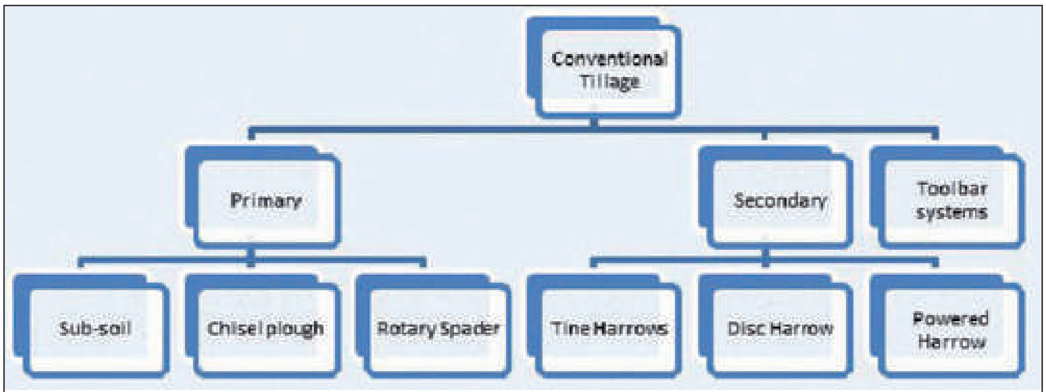

Figure 3 - Arrangement of conventional tillage implements

Traditionally, primary cultivation has used sub-soilers working at 30-60 cm depth to fracture and loosen subsoils when they are perceived as compacted and hindering root growth and is typically only done occasionally, as it is time, labour and fuel intensive. Generally, mould-board ploughs work to 15-30 cm depth to bury residues and start forming a seed-bed. The chisel plough works shallower than a sub-soiler but has a similar action to lift and disrupt compacted soil but, unlike the mouldboard plough, leaves the surface residue relatively undisturbed. This is followed by a secondary tillage implement that is shallower, 5-15 cm depth, wider and used faster to give much greater work-rates, offer better timeliness and prepare the seedbed for planting compared to primary tillage ploughs. Such secondary harrows are formed from vertical discs or frequently are a variety of tine forms and might be used several times, or in different styles, generally getting lighter and shallower, to produce a more suitable seedbed.

Timeliness to get the seed placed in a satisfactory seedbed at an appropriate time for satisfactory crop growth and yield is a major factor and is impacted upon by soil conditions, often a factor of the weather, and work-rate. The use of implements that use power from the tractor via the Power Take-Off (PTO) can enable a quicker or more thorough seed bed preparation. Although not common, there are rotary spaders that have a relatively slow turning horizontal rotor and "spades" that can almost simulate the action of a manual spade for primary tillage. More common and often used for secondary tillage are rotary cultivators, again with a relatively rapidly-turning horizontal rotor that cuts into a shallow layer of soil and breaks it and mixes it to get a fine seed bed. The "power harrow", also generally used for secondary tillage, has many vertical rotors with tines that create a "stirring" action in the soil.

Bed-forming ridging bodies are used to form beds for deep rooted and field vegetable crops including sugar beet, potatoes and onions. The rotary cultivator is often used in a combined machine with ridging bodies for this purpose. As with all primary and particularly secondary tillage implements the preferred implement depends on many factors, but obviously what the farmer has readily available is crucial. This will depend upon implements available from local dealers, those favoured by neighbouring farmers, soil type and condition and, importantly, what the following crop is, are likely to be the main factors.

The development of single-pass combination-cultivator systems to carry a variety of implement types for primary tillage (with chisel plough tines) and/or secondary tillage with discs and/or tines has become very noticeable in recent years to help timely soil preparation and is more readily achieved with the larger, more powerful tractors available. These combination-cultivators are often too heavy to be fully mounted on the hydraulic lift, in which case they are trailed. Not only are current tractors powerful but they are also heavy, to provide the traction necessary for pulling the larger trailed implements without undue wheel-slip.

Figure 4 - Rotary cultivator with bed forming ridging bodies for deep rooted vegetables

Figure 5 - Compact combination cultivator with lifting tines to disrupt shallow compaction, scalloped discs for incorporating residue and a firming packer

However, another recent development has been guidance systems, generally known as GPS, that indicate to the driver, or automate, more precise steering of the tractor. The impact of these on tillage systems is large, especially for those implements that are easy to overlap. It is difficult to manually steer to butt up to the previous pass without an overlap, which is often 5% or more of the working width. The guidance systems greatly help reduce the overlap with an immediate saving in time and fuel. The more precise, automated systems using an RTK (Real Time Kinematic) correction can be accurate to within 1 cm and these do enable long trailed combination-cultivators to be used in a simple "S" down the field, leaving un-tilled strips exactly the width of the implement. The tractor and implement can then work back up the field cultivating precisely the un-tilled strips. Not only does this avoid any overlap which wastes fuel and labour and time but it greatly eases the headland turns, as the tractor can take a steady radius turn without doubling back in a wider headland to be able to butt up to the previous worked strip.

Non-conventional tillage systems

These generally have a common theme of reducing the amount of tillage undertaken and this is often to reduce costs, improve productivity by being more timely or by improving the soil structure and fertility.

Minimising tillage, Min till, can be done by using conventional tillage implements but considering their use more thoroughly and performing fewer passes. Often a chisel plough will be followed by shallow tines and discs, perhaps all on one toolbar to break up deeper compaction while mixing in the crop residue, to enable the drill to work without blocking the coulters and allow the seed to be placed at the correct depth and away from residues, that might decompose to form harmful compounds that inhibit germination or shelter pests, including slugs, and fungal diseases. The drill may be adapted with different, often disc type, coulters to cut through the residue that is not mixed deep into the profile, by a mouldboard for instance. As always the type and number of tillage operations are determined by the farmer from his experience, information, available implements, crop to be planted, soil type (clay-loam-sand) and condition (wet, dry, friable).

No-tillage systems often involve very specialised coulters that may be disc or tine and that are particularly adapted to the local soil type and condition and, as well as the crop to be planted, also the preceding crop and the form of residue left. No-tillage systems, and reduced tillage systems to a great extent, do rely upon effective herbicides to control weeds, and other pesticides to control slugs and fungal diseases may be required more frequently. The early direct-drills developed in the 1970s were able to use a triple disc coulter where the disc diameters were relatively small, as the stubble from a preceding cereal crop would have been cut short and straw removed for stock bedding or even burnt off. Now that straw is frequently chopped and spread, the coulters on a drill for use in a min or no-till system will be larger, probably have more elements, including tines and disc combinations, and be better suited to clearing residue away from the planting strip.

Strip tillage systems can be seen to be a combination of reduced tillage and min-till systems. Only a narrow strip is tilled, typically for those crops on wider row spacings such as maize and sunflower. These implements will have tillage elements including finger wheels to clear residue, tines and discs and coulters and then seed covering elements and firming wheels or rolls. As can be appreciated this is actually a planter combined with cultivating elements, that have to be combined on one implement to ensure that the "strip" is cleared, cultivated, planted and completed in one pass, to ensure that the cultivating and planting positions coincide.

Indeed, in such systems the cultivating and planting elements are integrated and the implement becomes a "cultivator drill". There is a more detailed discussion of the planting elements and systems below.
Controlled Traffic Farming, CTF, is really a very old system. Anyone with a garden or allotment has heard of and probably uses a permanent bed system, in which they try to stand only on pathways around the bed and allow the soil in the bed to stay loose, friable and free of compaction, without regular deep digging, encouraging plants to root deeply for moisture and nutrients and produce productive crops. A research programme [15] at Silsoe Research Institute quantified the negative effects of running on soil and causing compaction. This led to the trialling of wide-span, gantry systems, but although the advantages were significant the complexity of such a system tractor severely limited its take-up. However, in Australia, farmers were used to having early self-steering systems and adapted standard tractors to 3m-wheel track widths, gathering some of the benefits of the gantry system but with less of the inconvenience of the wide, purpose–built, machines.

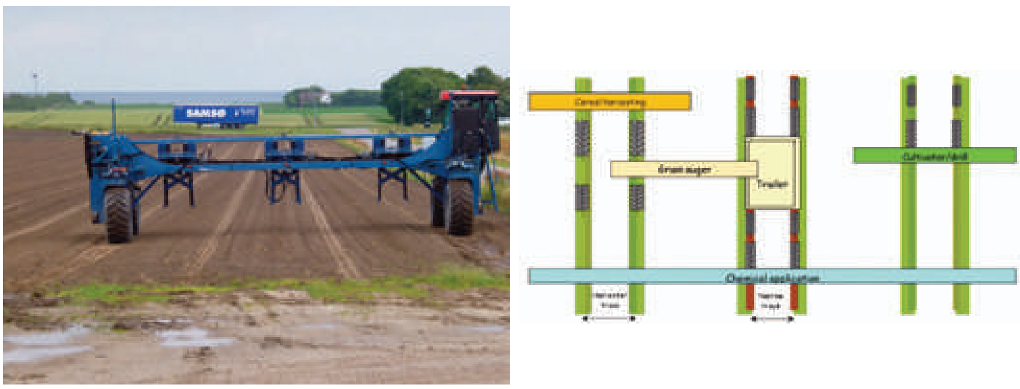

Figure 6 - CTF vehicle trackways showing how the harvester, trailer, cultivator-drill and chemical application use permanent trackways *[Source: 15]*

The arrival of auto-guidance with RTK precision gave a greatly renewed interest in CTF. It was now possible to use a standard tractor, although great care has to be taken over the track widths of all implements and combines, as well as components such as combine unloader spouts (**Figure 6**). It is often several years before a farmer has the right equipment to convert to CTF using permanent trackways and allowing the soil between to become more friable and easily tilled, with typically only about 15% of the field compacted [15]. Many vegetable growers in the Netherlands and elsewhere still use 3m tracks on their tractors, but often this is only used for a season's use of beds (seasonal CTF) before being ploughed. However, there are permanent CTF systems used on vegetable farms and often mixed in with cereal production. CTF can appear to be a complicated system and needs care and expertise to implement although, for the most part, the tractors and implements are near standard. This is an exciting development and is expected to become more widespread, as farmers look for ways of looking after their soils and yet have good yields from sustainable intensification. More information is at www.smartagriplatform.com/ctf.

Conservation agriculture (CA) again has been around for a long time and is promoted by the UN's Food and Agriculture Organisation (www.fao.org/ag/ca) particularly in emerging nations and by the European Conservation Agriculture Federation (ECAF) (www.ecaf.org) as a way of achieving sustainable and profitable agriculture and subsequently aims to improve the livelihoods of farmers through application of the three CA principles:

- minimal soil disturbance;
- maintenance of permanent soil covers and
- cropping system diversity, (crop rotations).

It will quickly be realised that the equipment needed for CA is basically the min and no-till implements described above, but incorporated into a complete system, taking into account rotations and permanent ground cover that will often require adapted planting equipment to deal with the residues and cover crops with, ideally, no tillage, although many planters, especially for wider row spacings in maize and sunflower, will be close to the strip-till implements described above.

There are many other developments to tillage equipment that are often forgotten about. These include developments in design, such as using CAD/CAE (Computer Aided Drawing/Computer Aided Engineering), which enables less prototyping and more accurate and rapid manufacturing. This enables equipment to be more closely adapted to specific local soils and cropping systems and not only for in-field use, but also for the folding systems that allow narrow transport widths for equipment with really wide working widths. Improvements in materials, such as through-hardened steels, give longer life to soil wearing parts and designs that allow much easier changing of wearing parts, through simpler fixing systems, are particularly important on these extra wide implements.

Future of Tillage

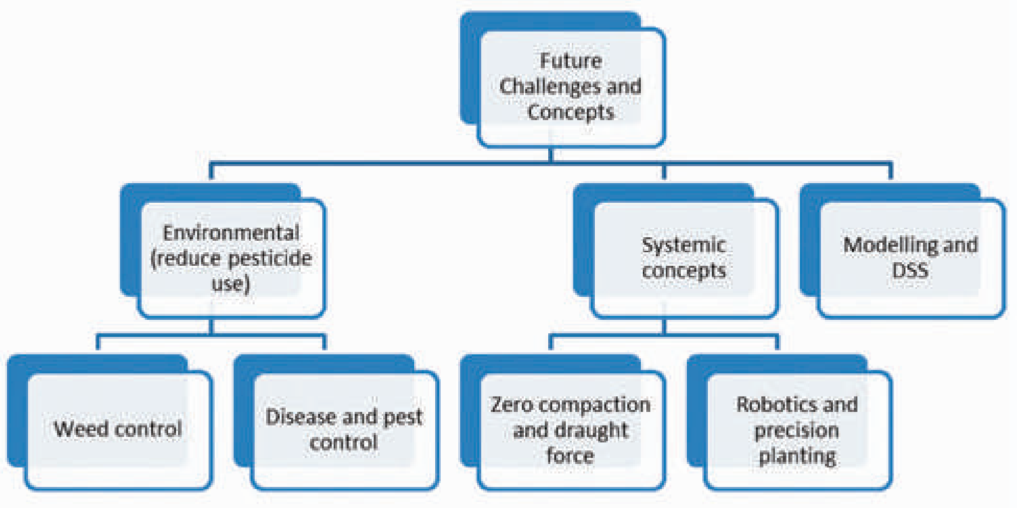

Figure 7 - Future challenges and concepts

The future holds many challenges for tillage systems. In the short term there is the likelihood of banning the herbicide glyphosate and the impact that will be seen on the probable increase in tillage systems to control weeds, whether before planting or during crop growth. To some extent the increase in organic production has already had an impact, leading to the development of "robotic" weeders that use imaging systems to control the inter-row, and with some machines, the inter-plant (intra-row) weeds.
There is also the problem in some parts with herbicide tolerant weeds, such as black-grass, becoming so problematic and yield reducing that farmers are deliberately sacrificing patches of crop by using broad-spectrum herbicides that kill the black-grass for the benefit of future crops. Such an action is easier with Smart Farming Technologies, that allow field scouting and mapping of the black-grass infected areas, and then sprayers with section control to apply the herbicide only on the patches of black-grass.
Decision Support Tools, including Apps on Smart-Phones, will help farmers determine what tillage to use in a management system by modelling tillage, planting time, rotations and crop varieties. An example is Crop-Protect, developed as an App by Rothamsted Research Institute, https://croprotect.com, which suggests management methods for black-grass control. Similar issues exist with the increase of damage caused by increased numbers of grey field slugs in arable crops, following the widespread banning of methiocarb in Europe from 2014. Rotational ploughing is part of the suggested management procedure to limit the crop damage caused by these pests.
Immediately there is always the problem of undoing the compaction caused by field operations. Chamen [15] showed that around 65% of the energy used in tillage is just to undo shallow compaction, while Blackmore and Godwin have surmised that undoing deeper compaction, for instance from heavier, self-propelled machines, could make this figure about 90%. CTF has been mentioned as one way of minimising the compacted area of a field and controlling exactly where it is. However there is still scope to develop concepts that aim for zero compaction. Small vehicles with very low ground pressure are able to run on soil at field capacity without causing compaction. Such lightweight vehicles could carry suitable planting equipment and conceivably lead to near-zero draught systems, only low rolling resistance needing to be overcome, for instance, as demonstrated by a Finnish team at the 2015 Field Robot Event. That team used rechargeable electric hand tools with normal woodworking helical drills to open up a hole suitable to plant an individual seed while the vehicle was stationary. Conceivably this could be used with widely spaced, high value plants and the vehicle would be a small autonomous robot able to work for near 24 hours each day. It will be appreciated that effectively there is no tillage, it is practically purely planting. Perhaps tillage will become an outmoded concept and the aim will be to have the seed planted in the ground with absolutely no horizontal force to invert, cut, shatter or mix the soil. This gives plenty of scope for agricultural engineers over the next 25 years to discuss, experiment, study, invent and develop tools and systems to improve tillage.

Sowing

The dominant objectives of the sowing operation are twofold. Control of ***seed rate*** related to uniform spatial placement as a superior requirement and ***seeding density*** to ensure the desired number of plants per area. The latter has a crucial impact on crop yield and depends on crop species and varieties. Traditional adjustment of seed rate is employed by bulk dosing with seed rollers as the metering device. As a result the longitudinal distribution of seeds in the row is uneven and follows a hyperbolic frequency of seed distances. Placement of seeds is a matter of horizontal distribution, but the vertical placement is a second basic condition for advanced sowing technology, requiring precise control of ***sowing depth***. Embedding of seeds is related to soil contact, for supply of water triggering the germination, and is limited by the germination forces of the seeds, allowing only shallow soil covers. A special challenge is the embedding of fine seeds e.g. medicinal plant seeds with sizes below 1 mm, requiring shallow sowing depths.

Apart from these basic tasks of sowing, a trend in innovation of seed drills is to higher capacities. Increasing capacity was realized in the past mostly by enlarging the width of the drills. The major trend of recent years, however, is to increase the speed, which is associated with more difficulty in depth control of the openers. Operating with higher speeds requires, as far as precision sowing is concerned, a high frequency of singulating the seeds. Mechanical singulating becomes inappropriate, while pneumatic assisted singulating devices tend to become worse in longitudinal distribution of seeds, which is not acceptable for row crops.

For the major crops in Europe traditional seed drills are used. This machine type is relevant for approx. 12 million farms in the EU and these drills are still dosing the seeds using studded seed rollers. As a consequence, the distribution of seeds in the row is not optimal. An increasing share of the drills is equipped with rolling shares, with one or two discs opening the soil and placing the seeds in a furrow. Zero tillage or direct sowing is estimated to be still quite small in Europe, even though the advantages of conservation and zero tillage with regard to improved soil structure are well known.

Uniform depth placement of seeds was, and still is, an item for improvement on sowing equipment. Precision drills are equipped with gauge wheels in front and behind or beside the seed opener. Studies resulted in the desire to position the gauge wheels near to the seed opener. Later tandem suspensions with good

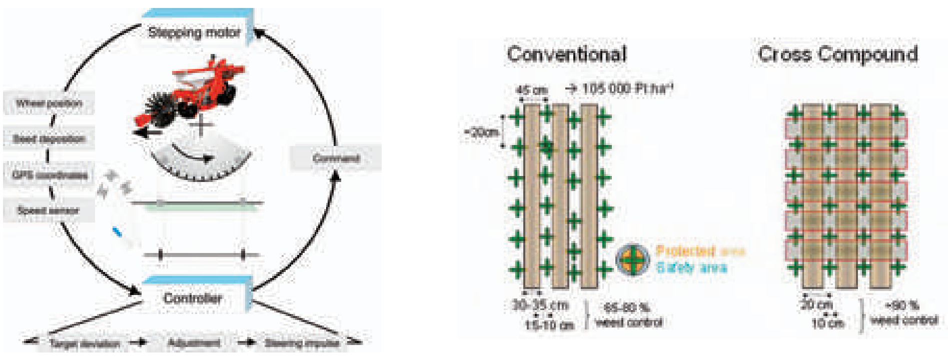

Figure 8 - Left: Schematic layout of a seed drill with position controlled seed grain placement;
Right: conventional plant positions and coordinate controlled plant positions with bi-directional rows
[Source: 52]

depth placement of seeds became of more interest and were implemented on precision drills [26]. Mechanical precision drills, mainly employed for sowing of sugar beet, started to use electric motors to drive the cell wheel or disc. Electrical drives are the precondition for position controlled sowing by precision seed drills, generating triangular or rectangular formations (**Figure 8**) and synchronized seed placement beyond the drill's working width [52]. Square placement of plants also fits well to applying crosswise mechanical weeding [25, 32]. An additional feature is that of section control to avoid overlapping of seeds with the headland rows.
Recent developments in seed drilling are to improve the longitudinal distribution during sowing of cereals and oilseed rape. Sensor systems for particle detection are applied for seed flow control, with the aim of further automation of seed and fertilizer placement. Different systems have been introduced for counting single seed grains in the seed pipes. The ultimate scope of sowing is to meter the seed rate by grains per hectare, to control the number of plants directly. Crops such as maize, sugar beet and soybeans need accurate spacing between the seeds to develop higher yields. Central singulating of seed grains was introduced by Kverneland and launched on market by Amazone. The pneumatic assisted metering drum singulates the seeds on the surface of a perforated drum and holds them there by a pressure difference between the outside and inside of the drum. The pressurized air is subsequently used to transport the singulated seeds in pipes to the share, where they are injected at high speed into the soil while caught by wheels for precise placement in the seed furrow (**Figure 9, left**).
Attempts are made to increase field capacities of precision drills by ***higher speeds***. Horsch developed a drill with a central seed supply by air, but singulated the grains at the share (**Figure 9, right**). The singulating device is able to separate the grain with high frequency in a disc assisted by differential air pressure. The operating speed is up to 15 km/h, resulting in placement accuracy as required for maize. A similar drill is offered by Vaderstäd, also using a singulating device on each share for small row distances (< 20 cm).

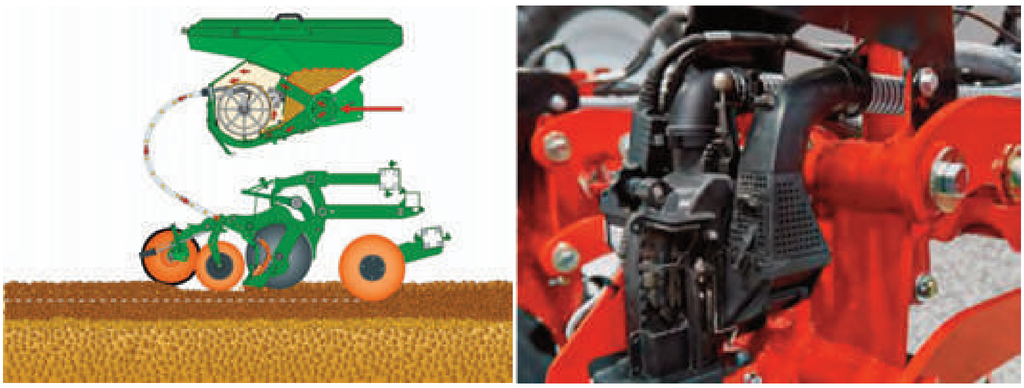

Figure 9 - Left: central singulating drum and seed transport after singulating, Amazone EDX *[Source: Amazone, Hasbergen, Germany]*; **Right: Horsch Maestro with singulating device on the share suspension with pneumatic seed supply from a central hopper** *[Source: 52]*

John Deere launched a new precision seeder for ***high speeds*** up to 15 km/h. The conventional pneumatic singulating device transports the seeds after leaving the cell disc by a brush belt to the share. Thus the biased seed spacing due to free fall in seed pipes is avoided. The speeds of the belt and of the seed disc are synchronized with the forward speed.

Strip till has been attempted for cultivation of maize and sugar beet in Europe. This zonal cultivation method is tested in two ways; the single stage system pursues a deep loosening of soil only in the zone of the rows by tines. Subsequently, for seed bed preparation, re-compaction and seeding, tools are embedded in the implement. The other, two stage, method is to loosen and till the soil in strips in autumn, while in spring the seeds are sown in the strips prepared in autumn using RTK-GPS for tractor guidance following the rows.

Plant protection device

Apart from suitable embedding of seeds and supply of necessary nutrients, a third range of technological equipment is directed at plant protection. In Europe, plant protection agents are predominantly applied by spraying of synthetic pesticides. The main trends of the last 25 years are on higher precision of spray applications and operator safety. An increase in efficiency is expected in consideration of the locational variability and of diverse crop parameters. There are no statistical approved data on losses and over-sprayed applications, but estimates indicate that more than 50% of the applied pesticides are not effective. Research focuses on two areas to improve efficiency. One is herbicide application by means of weed recognition systems and patch spraying of herbicides, to replace uniform field spraying, and early stage recognition of fungal attacks, to avoid prophylactic fungicide spraying. The latter is of special concern for protection of vineyard and tree crops, which generally use fan assisted airflows for the chemical to penetrate the canopy. For both applications, loss due to drift has been the subject of developments in the last few decades.

Increasingly, the application of pesticides is regulated by European policy. The sustainable use of pesticides has been regulated by directive 2009/128/EC of the European Parliament. This includes a commitment, by the member states, to adopt national action plans on the sustainable use of pesticides, and provides regulations for expertise of operators and for testing of plant protection equipment. The Directive 2009/127/EC requires, with regard to machinery for pesticide application, that new plant protection equipment must meet the European standards and must be CE marked.

The entire program for control of the pesticide spraying sector has a three pronged structure:

- training of operators;
- new equipment must fulfill the requirements of EU-directives;
- regular and mandatory inspection of spraying equipment in use.

The entire time, covered by this book on plant protection equipment, regards facilities to protect the environment and operators. Special emphasis is laid on reduction of drift, residual quantities and contamination of operators. Voluntary checks of field sprayers under practical use have become increasingly popular and nowadays a regular check of the spraying equipment is undertaken in agriculture.

Plant protection sprayer equipment is characterized by a trend toward self-propelled sprayers. The largest market is France with 11,000 units sold in 2008.

Balsari [4] reported on the 10th Club of Bologna meeting that the evolution of sprayer technology is concentrated on point source and diffuse source prevention, reduction of pesticide application and improvements to operator safety. Prevention of point source contamination is covered by devices for advanced filling and rinsing. To ensure complete rinsing, the sprayers are equipped with automatically controlled systems to clean the sprayers effectively. The diluted spray mixture remaining in the sprayer tank has to be disposed of in the field. Additionally, the manufacturers take care to reduce the residual spray mixture in the sprayers to a minimum. Field sprayers are increasingly equipped with a rinsing and residue management system, for easy and safe operation by the operator.

Prevention of diffuse source contamination is a matter of droplet drift under a size of 100 µm into boundary areas. Drift reducing nozzles were designed, with atomizing chamber generating more droplets with diameter greater than 100 µm. The liquid passes a diaphragm, feeding the nozzle chamber with a coarse atomized jet. These injector-nozzles are in general flat-jet nozzles, having additionally a lateral opening where ambient air is sucked into the liquid flow. With regard to biological efficacy these low drift nozzles have no significant drawbacks, but drift reduction accounts for up to 75%. According to the requirement of drift reduction, a classification of nozzles with levels of 50, 75 and 90% of drift reducing effect has been introduced, and is presently applied when sprayers are equipped for in-field spraying. Apart from droplet sizes, wind affects the drift of spray significantly. **Figure 10** outlines permitted wind speeds for different levels of spray volume, as reported by Ripke et al. [47].

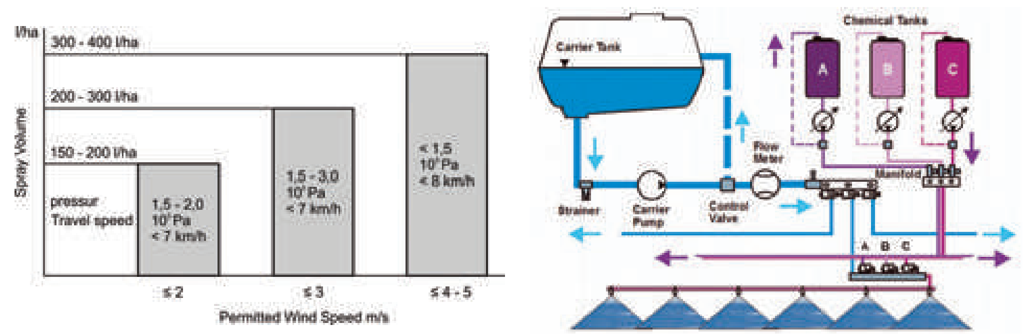

Figure 10 - Left: Recommendation of spray volume related to wind speed *[Ripke et al. , 1991]*;
Right: Schematic layout of de-centralised system for spot spraying with variable rate application for 3 different active agents *[Source: 55]*

In order to apply pesticides precisely, GPS and GIS are useful measures to map field treatments and plan variable rate applications according to the crop protection targets. In arboreal crop applications, significant reduction of pesticides is expected by modeling. The models provide information about the disease, size of canopy and wind conditions to meter the volume rate using conventional or anti-drift nozzles. To achieve higher levels of savings on pesticides variable rate and site-specific spraying is an adequate technology. The direct injection system as outlined in **Figure 10 right** meters the pesticide into the carrier flow near to the nozzle, which allows low reaction times. Three different pesticides can be applied independently and the water, as the carrier liquid, is kept separate until mixed with the pesticide near to the nozzle. Dosing of the pesticides for each nozzle is necessary and due to small flow rates is still a technical challenge. The reaction time of 500 ms which is needed until the correct concentration of water and pesticides is obtained corresponds to a travel distance of 1.5 m [6, 59]. The system as outlined in **Figure 10 right** meters the pesticide volume rate by pulse width modulation, which is independent of carrier flow rate, and the constant pressure avoids changing the droplet size spectrum of the nozzles.

Pulse width modulated nozzles, as well a new technologies for tank mixed/conventional sprayers, for variable rate spraying have just recently appeared on the market [62].

Sensing of weeds, for real-time, site-specific and variable rate spraying, was a research topic in the last decades. Crop proteins using gene-technology can be detected by light amplifying sensors [36]. Image processing systems have been developed by Sökefeld and Gerhards[55] for recognition of weed plants, including a differentiation of weed species, and are now available as H-Sensors (Herbicide sensor). Progress in recent years has been made by smart cameras, with embedded hardware for image processing in the actual camera head.

Sensors based on lasers, ultrasonics, visible light with cameras as well as infrared systems have been developed to reduce pesticide use by target spraying in orchards. Sprayers are equipped with several sensors which control several nozzles with regard to non-uniform tree distances, missing trees and tree height, and include nighttime operations and switching the flow off during headland maneuvers. Walklate and Cross (2013) undertook an approach by modeling, considering the tree foliage by density, height and penetration depth of the spray plume, for higher accuracy in orchard spraying.

Mineral fertilizing device

Fertilization of crop plants is a measure of high yielding agriculture and a condition for providing a supply of nutrients for the world`s population. But providing nutrients using fertilizers aimed at high crop yields is adversely affecting the environment. Site-specific fertilization therefore has the objective of matching the supply of nutrients with their removal, and includes differences in soils as well as in crops. In the last decade numerous approaches to sensing of soil and crop plant properties for site-specific fertilizer application have been tried.

Heege [27] emphasized three distinct approaches for generating suitable signals from sensor equipment:

- recording of yield of previous crop and related nutrient removal;
- electrochemical sensing of nutrients in soil;
- sensing of nutrients in soil and crop plants by optical reflectance.

As a prospect in precise fertilization the distinction between nutrients is stressed:

- for phosphorus and potassium the application according to mapped removal by previous crops has good prospects;
- for nitrogen application excellent prospects exist for online sensing by reflectance of the crop.

For the control of soil pH, via calcium and magnesium supply, mapping of ion-selective-electrodes is promising [27].
Nitrogen supply requires high demands on distribution quality and timeliness of spreading. FAO-Stat indicates for 2002 11 million t of nitrogenous fertilizer was used in the EU. Mainly this N-fertilizer is distributed by centrifugal spreaders. The European market sold 31,000 pieces in 2008 which were the highest annual sales in recent decades. Manufacturers have been requested to offer spreading devices with optimal distribution and for an increasing range of fertilizers in terms of quantity and quality.
Balsari [3] explicitly stated, in his contribution to the Club of Bologna, the incorrect application of fertilizers by reason of inadequate application methods and techniques, and emphasized that electronics are crucial for advancements in spreading technology. Control of operating parameters, including fertilizer application data transfer into farm management systems, played a fundamental role in the evolution of spreader technology.
The most used and sold type of spreader is the centrifugal fertilizer with two discs. The trend is, as in other sectors, of mechanization characterized by increasing capacity of the implements. That affects the hopper volume (tractor mounted up to 4.2 m^3) and working width (up to 54 m). Accurate border and boundary spreading and ease of operation have become major features of spreaders in recent years. Different systems are offered by the manufacturers, systems change the trajectory of the fertilizer granules in flight by mechanical trimmers, reducing or even reversing disc revolutions on the border of the field, especially important near watercourses, or according to the inclination of the machine. The conventional propulsion by mechanical gears and shafts has been replaced by hydrostatic drives, allowing continuous change of disc revolutions. By assessing the hydraulic pressure drop between motor-inlet and outlet the mass flow of fertilizer is controlled independently using calibration. Electrical drives are offered as well, but the spreader has to be equipped with an electric generator, as the tractor's electrical supply will not cope with the demand of the spreader's electric motors. By means of the voltage drop in the electric motors, the drive torque of the spreader discs is monitored and used to control the massflow effectively. Intelligent regulation by electronics calibrates the entire system at short, regular intervals. For the application rate control a high share of new machines sold are equipped with weighing systems. They differ with regard to the number and position of weigh-cells embedded between frame and hopper.

Figure 11 - Left: Spread fan monitoring using Radar sensors source *[Source: Werkbild Amazone, status public]*;
Right: Test station for spreading quality of grained fertilizer as designed by Irstea *[Source: Irstea, 2016]*

Section control to adjust the shape of the spread fan in wedge-shaped fields is an option which is offered by the manufacturers of twin disc spreaders. For monitoring the spread fan, microwave sensors are used to assess the transverse distribution. The spread fan is checked for both left and right disc, and the metering device is corrected independently (**Figure 11, left**).
To test the operational quality of spreaders an advanced testing facility has been designed by Irstea at Montoldre in France. The spreader is moved rotationally and a stationary collecting channel, the size of the spreader`s working width, collects, accumulates and measures the mass of fertilizer granules during rotation of the spreader covering the entire spread fan. The fertilizer masses are allocated to the spreader position and the distribution is calculated and displayed (**Figure 11, right**).

Grain harvest

Combines are one of the key machines in agriculture. With the modern machines of today one man can harvest 20 ha and more per day! In the last 25 years the market for these machines has changed. While the number of machines decreased, the size of the machines increased. On the example of the European and the North American markets a decrease of approximately 1/3 of the numbers from 1990 can be seen to date, **Figure 12 left**. Additionally, this trend is superposed on huge fluctuations due to actual market effects. Parallel to this development the capacity of the machines has increased. It can be shown, based on the example of the German market, that the engine power has more than doubled in the last 25 years, **Figure 12 rigth** [13]. The increase in capacity is not only based on the increase in size and engine power. A lot of detailed improvements have been made with regard to i) the machine processes like threshing, separating and cleaning, ii) operation of the machines and iii) the automation of several tasks and processes. Parallel to these developments the reduction in fuel consumption and in engine emissions has been realized, the second according to the different regulatory requirements in the different markets of the world. All these improvements are reported in detail with numerous references annually in the Yearbook of Agricultural Engineering.

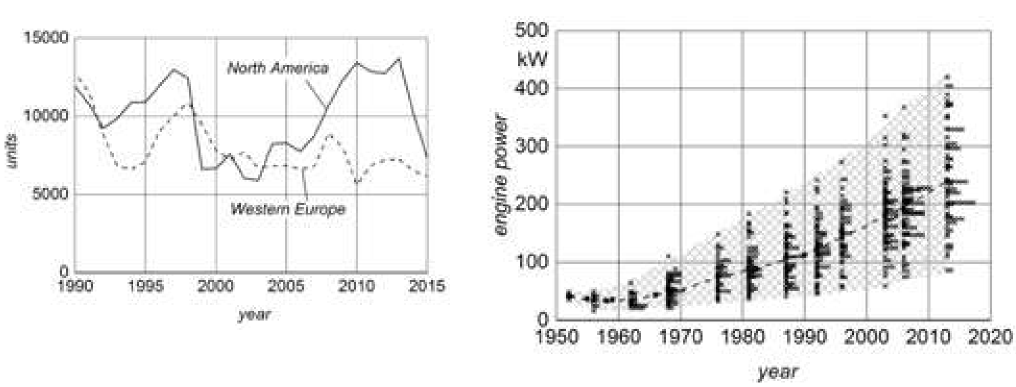

Figure 12 - Left: - Sold units of combines; Right: Engine power of combine *[Source: 12]*

The threshing, separation and cleaning systems of combine harvesters have improved on the one hand by the optimisation of details in the different units. On the other hand, additional separation drums in the threshing unit and the replacement of straw walkers by separation rotors and the optimization of the mechanical and pneumatic parameters of cleaning units has improved the performance of combine harvesters. As a result of these developments, today's combine harvesters can have nearly doubled harvesting capacity in machines with the same physical size.

The combine operator has the task of realizing the installed capacity during the whole harvest. To support him in his task extensive systems have been developed. First, the operator has to be informed about the actual performance of the combine harvester. For example, drive shaft monitors and yield loss sensors indicate changes in machine performance. Sensors for grain yield and moisture help to interpret the information. The displays changed from analogue to digital devices and graphical instruments in on-board computers. Context sensitive information can be shown on them and the operator can change the machine settings easily by ergonomic levers and switches. Electric and hydraulic actuators ease the adjustment of the machine settings, and enable automatic adjustment of the whole machine according to the type of crop being harvested, simply by pressing one button.

Secondly, the operator has been relieved from routine tasks. Control of the header height and lateral inclination enables exact and continuous following of the contour of the field. A prominent improvement is the development of automatic steering systems. Three different solutions are available today: for corn harvest a mechanical sensor touches the stalks of the plant, for other plants laser scanners detect the edge of the standing crop in front of the header and GPS-based systems determine the position of the machine. Based on these different sensor signals, automatic steering is made possible and the driver is relieved of the task. In addition, a more continuous crop flow through the machine, full use of the header width, improved yield sensor performance and fewer headland turns are achieved.

Thirdly, automatic optimization of the machine adjustment according to actual harvest and crop conditions improves the use of the combine harvester independent of the operator's experience. For example, the throughput control homogenises the load of the different process units in the machine and helps to operate continuously on a high throughput level throughout the day. The ground speed is therefore adjusted according to the load on the feeder housing or on the threshing drum. In combination with signals from the grain loss sensor or the yield sensor, both measured late at the end of the crop path through the machine, the throughput control can be improved. Other examples for the automatic optimization of machine settings are setting of the concave clearance depending on the forces acting on the concave mounting and the side-hill and up- and down-hill settings of the cleaning unit and/or the whole machine.

Current research on the improvement of combine harvesters is directed further on these three topics. In addition, cooperation of the harvesters with transport devices and improvement of the performance of the whole fleet and not only of one machine is on the list of researchers and developers. Both together have achieved important results, not only to improve machine performance, but also to reduce engine emissions and fuel consumption.

Sugar beet harvest

Sugar beet is harvested in the EU on an area of 1.56 million ha, of which France has 372,100 ha, Germany 372,000 ha and Poland 190,000 ha in 2014, with an average sugar yield of 11.1 t/ha [64]. In 1992 the EU had an area for sugar beet of 1.98 million ha and the sugar yield was on average 8.07 t/ha [6].

The prevailing harvest technology is the six row harvester with scalping of the leaves, lifting and transporting the beets to the end of the field in a single pass (**Figure 12**). The range of harvester types offered by the four manufacturers has been extended, whilst the number of harvest machine manufacturing companies has declined in the last 25 years by around 15. In 2015 three leading manufacturers produced two- and three-axle tankers with 6-, 8-, 9- and 12-row headers with either a topping or defoliation device. The machines are equipped with bunkers of a capacity ranging from 25 to 40 m^3, whereby the larger bunker volumes are based on vehicle chassis with three axles. Another machine type, used in France, is a self-propelled harvester scalping and lifting the beet, but these are conveyed by tractor-drawn trailers, transporting the beet to the headlands or to central stockpiles. Diesel engines with power of 360 to 450 kW are used to drive the tankers, and all moving parts of the machines are driven by hydrostatic motors.

The topping devices are designed for minimum cut. The cutting width is triggered by the height of the beet above the soil surface. The cutting device works for deep seated beet with a narrow head cut and considers deep-seated beet as small. Large beet with a large height is treated by a greater head cut section, which is increasingly viewed as a critical factor in harvesting the beet.

The prevailing lifter is the Polder-share, which is self-aligning. Only the Grimme harvester Maxtron uses hydrostatically driven spoked Oppel wheels. This harvester type has a rubber belt crawler-track with a twin tired rear axle to spread the weight. Considerable technical success was gained by a new generation of tires (Michelin, Ultraflex) that are now approved for regular use at an inflation pressure significantly below 2 hPa.

Beet harvesters are tested at the *Beet Europe* event and evaluated by mass losses, topping quality and soil tare. The last test performed with 9 self-propelled tanker type harvesters in Seligenstadt, Germany had a beet mass loss on average of 3.9% and more than 77% of the beets were 'well-topped' or 'correctly' defoliated. A

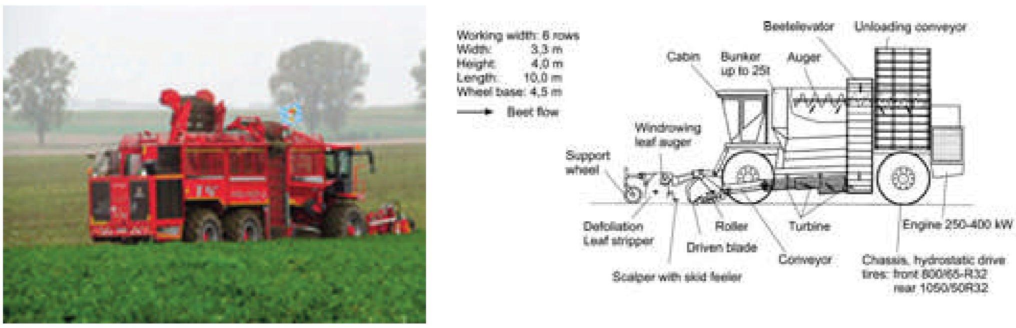

Figure 13 - Left: Sugar beet harvester 2015, six row header 3 axles and bunker capacity of 40 m^3; Right: schematic of a sugar beet harvester with main components in 1992 *[Source: 51]*

trend towards a flat topping cut can be observed, as a result of which on average 19.2% non-topped beets or insufficiently defoliated beets occurred. Such a high value for this category of topping quality was not found in previous tests. The soil tare percentage was 11.5% on average. (**Figure 13**).

In comparison with the evaluation made in 1992, where 21 harvesters were tested, including two and three row trailed machines, self-propelled six-row tankers and six row harvesters without bunkers the mass losses were, on average, 3.3% of the yield, soil tare was assessed at 4.7% and well topped beets amounted to 83,6% [33]. This suggests that development of the new minimal topping techniques has apparently not had a beneficial effect.

The development of performance of sugar beet harvesters is outlined in **Figure 14** by speed of the harvesters when in test operation. As compared to 1984, which was the first test with standardized test conditions, the speed increased by more than 30%. In the same period mass losses (broken tips, lost beets) and soil tare decreased in a range between 30% and 50%. Soil water content is outlined in the graph because, to a large extent, soil tare depends on the soil conditions during harvesting. In summary, the development of sugar beet harvesters is characterized by remarkably higher mass flow due to higher speed and to higher yield, with simultaneously lower mass losses and soil tare. In conclusion, cleaner beets are delivered to the sugar factories, with lower residues which have to be returned to the fields.

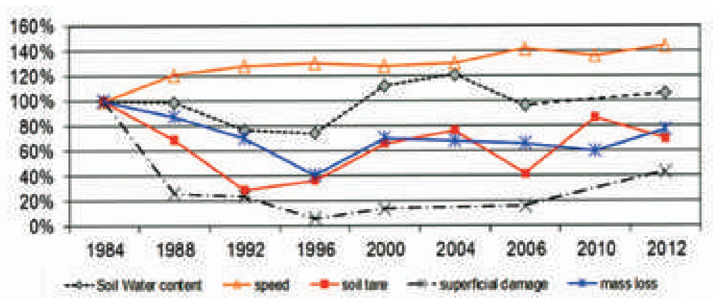

Figure 14 - Operation speed of harvesters, soil tare, soil water content, mass loss and superficial injuries of sugar beets after harvest 1984 to 2012, tests in Seligenstadt and Lelystad
[Source: 51]

Reduction of soil tare is a problem of major concern in recent decades. During this time the storage and loading by cleaner–loader came into use and is applied increasingly in European countries. The effect of cleaning arises from the beets being stored in piles, where the surface of the tap-root dries out. Subsequently, the separation of adhering soil is eased when the beets are loaded onto trucks by cleaner loaders. These cleaner loaders appeared in the 1990s as self-propelled and self-loading machines [66].

ELECTRIC POWER FOR MOBILE MACHINES

The electrical power supply of farms has developed in the twentieth century and was a major progress for on-farm operations. The use of electricity both for stationary drives as well as for the control of technical processes in livestock farming is still increasing. In field work, electrical drives for machines have appeared only in the last ten years and are still under innovative development. The Club of Bologna discussed, at its 2010 event, this issue as a new technology. Möller, Noack, and Rauch [39, 40, 44] reported on trends in automation and

electrical drives in agricultural field machinery, outlining the already existing electrical and sensing techniques as well as giving visions of digital agriculture. Electrical drives are expected to substitute mechanical and hydrostatic drives, which are dominating the propulsion technology in agricultural implements nowadays. As major advances, the direct control by digital signals, reasonable power to mass ratio for small units and adequate torque characteristic is pointed out, as well as power connection by cables allowing great design flexibility. Therefore electrical drives are predestinated to be applied in agricultural machinery, as they require multiple and distributed drives. As an example, most of the drives for metering of seeds in pneumatic drills and precision seed drills use electrical motors. However, for non-rotational motion hydraulic drives are still favored, and as a significant limitation for a wider use of electrical drives the lack of mobile electric power source is important. Working in the field needs a power supply on board; this exists through rechargeable batteries but these do not have sufficient capacity. As an alternative for the supply of remote electrical drives in agricultural implements, Buning [14] reported on a John Deere tractor equipped with an embedded electrical generator connected to a 40 V grid and with a maximum power of 40 kW.
Automation of farm machinery is based on developing and using information systems in agriculture (Smart Farming and Big Data). As most of the field operations are space related, the global positioning systems (Global Navigation Satellite System, GNSS) and Geographical Information System (GIS) are aiding control processes of agricultural machinery in field operations. Simultaneously, wireless communication of speech and digital data by GSM and WLAN/Wi-Fi from office to vehicle, vehicle to vehicle, implement to vehicle and finally man to machine contributes to automation, supporting the operation of machines working in the fields. A substantial precondition is the development of standardized data protocols and interfaces. Auernhammer had already proposed in 1983 the "Landwirtschaftliches BUS-System-LBS" which was internationally standardized in the last decades as the ISO-BUS but is still being revised.

ENERGY EFFICIENCY AND RENEWABLE ENERGY SOURCES

These issues are important for society, agriculture and agricultural engineering, and were also elaborated by Club of Bologna. Energy balances are throroughly elaborated in volume V of CIGR handbook series, which involved many Club members in its creation.

Energy Efficiency

Reduction of energy input in agricultural production and postharvest processes contributes to a decrease in use of fossil fuel reserves, costs and a saving of Greenhouse Gases (GHG-emssions). This is obtained by abatement of direct and indirect energy inputs, and a change of production technologies and systems. Every energy input reduction has a positive impact on the environment.
Examples of direct energy saving, first of all diesell fuel, are listed in the chapter on tractors. However savings are obtained also in other sectors. Typical is the reduction of fuel consumption for grain harvesting, reported by Bodria [11] (**Figure 15)**. The lowest specific fuel consumption has been, since 1957, reduced about threefold.

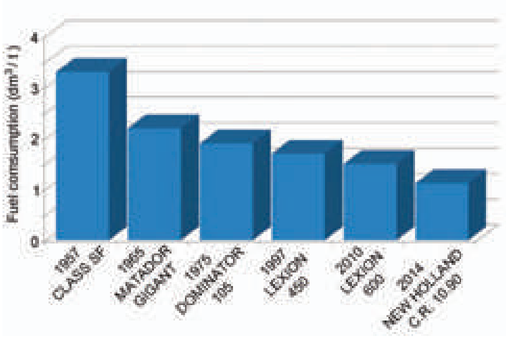

Figure 15 - Trend of specific fuel consumption for cereal harvesters *[Source: 11]*

In many cases the indirect energy inputs, fertilizer, pesticides, crop propagation material etc. have a higher share than direct energy use in total consumption. This is especially related to energy required for nitrogen fertilizers. The issue of fertilizer broadcasting precision was tackled by Balsari [3] and others. The newest development in the sector of mineral fertilizer spreading is adapting to site specific needs, and performed by application of Variable Rate Technology – VRT. One possibility, especially by using the spreader's electric drive, was reported by Rauch [44]). Further possibilities for savings include a combination of VRT spreader and change of nitrogen fertilizer amount based on on-line measured crop supply and needs (optical identification).

Further savings in direct and indirect energy inputs are enabled by application of global navigation satellite systems – GNSS. New achievements and precision are reported by Noack [40]. The relative error is, for a sophisticated system, reduced down to 2.5 cm, and this even allows pass-to-pass navigation in sowing of cereals. Due to the reduction in overlapping and headland turning there will be reduced fuel consumption per hectare. GNSS also enables a wider application of VRT, and mineral fertilizer savings, in a case of heterogeneous soil conditions, of up to 20%.

Pickel and Bellon-Maurel et al. [41, 7] presented Life Cycle Assessment – LCA, important for agricultural machinery, and, amongst other aspects, underlined the necessity of Global Warming Potential, i.e. GHG reduction related to energy.

Renewable energy sources

Positive effects of using Renewable Energy Sources – RES are well known, as is the obligation of EU and Energy Community defined by RED (RES Directive) 2009/28/EC.

In many countries the biggest potential RES are in agriculture and forestry. Agricultural machinery is used for collecting and processing crop residues. Different biomass conversions, important for agriculture and rural areas and standardisation of it, are reported by Riva [49], and for timber biomass and forest engineering by Spinelli [57].

Agricultural products and by-products are feedstock for biofuels. The activities related to biofuels started with the production and utilization of Fatty Acids Methyl Esters – FAME, commonly called biodiesel (although this name is properly used solely for rapeseed oil). Information on this kind of biofuel was reported by Best, Riva and Heinrich [8, 28, 48]. Fuel is standardized, EN 14214, and was used for tractors and other machinery and vehicles, but now primarily as a blend with fossil diesel, e.g. B5.

In the last decade tractor engines ready for commercial use of native (pure, neat) vegetable oils (rapeseed) have been developed. This has been presented by Ribaldone [45]. Also a German standard for

quality demands of this fuel, DIN V 51605 have been developed, and the development of EN and/or ISO standards is expected.
The RED, articles 19 to 21, and other EU documents, have defined the prerequisite for acceptance of biofuels as an RES. Since 2018 only biofuels and bio-liquids for which production and utilisation results in saving of GHG (expressed as CO_2 equivalent) of at least 60% compared to fossil fuels emission etalon (83.8 gCO_{2eq}/MJ) are treated as acceptable. Standard EN 16214-4: 2013 as a tool for performing LCA for biofuels has been developed. Fulfilling this request is difficult for biofuels based on feedstocks containing sugar and starch. This is why the second generation of biofuels (2G) or advanced biofuels are based on the use of lignocellulosic materials, e.g. crop residues and dedicated crops [17], and other non-food feedstock. Typical products are lignocellulosic bioethanol – LCB, synthetic fuel (BtL, Biomass to Liquid, Fischer-Tropsch fuels), and biomethane (upgraded biogas generated from non-food substrates).
The newest amendment to RED is Directive 2015/1513, which gives a reference target value for advanced biofuels of 0.5%, to be adopted by member states by 2020, and allows double counting of fuels from raw materials such as used cooking oils and animal fats.
Biogas production and utilization is widespread in some European countries. Riesel [46] reported on developments in this technology. Döhler and Paterson [18] emphasized the problem of utilization of energy crops, first of all corn silage, as a substrate, and the negative impact on CO2eq balance, but also the utilization of new substrates, e.g. sugar beet. The mayor new challenges are to use primarily wastes and by-products as substrates, find better possibilities for using the thermal energy, introduce flexible biogas production – demand led and more appropriate use of digestate The development of profitable mini and micro biogas plants is an objective for the future. Technologies for pretreatment of crop residues for biogas production are in early stages of commercial maturity. The generation of biomethane from biogas produced from crop residues seems to be a good 2G biofuel.

Figure 16 - First European LCB plant PROESA, Crescentino, Italy
[Source: M. Martinov]

DEVELOPMENT OF CURRENT RESEARCH AND FUTURE DEVELOPMENTS

Precision crop and livestock farming and robots

The precision farming concept emerged in the early 1990s, but it is by the early 1980s that the modulation of fertilizer inputs from soil tests began in the US [67].
Scientific works on precision farming led to development of an approach taking into account all the heterogeneities of a cultivated plot and acting appropriately to adapt the use of inputs, with strict cultural

needs limiting inputs, maximizing the income for the farmer while controlling the impact of cultural practices on the environment.
Precision farming is therefore "*the right dose at the right place at the right time*." It uses five major technological components that are geographic information systems, location systems, sensors, dose control devices and performance measurement systems ([43]. It takes into account three types of variability: the spatial variability, temporal variability and predictive variability. Indeed the choice of action to take and of the appropriate time and place is based on prediction models that can be influenced by weather conditions and other factors as accuracy [15,25].
The precision farming process, therefore, is initially measured by collecting the largest number of relevant data. Then the collected data is analyzed to decide and then act (**Figure 17**). The various components of the process result in research. Advances in data collection are developing new sensors or improving existing sensors. Data analysis progresses through the development of new methods of fusion of information from heterogeneous sources, but also through the ability to include these data in the time-space frame with geographic information systems in endless improvement. Improving decision making is based on the development of new decision support systems able to take into account an increasing number of important parameters. The precision of actions carried out by the machine implementing the decision is improving, thanks to developments in mechatronics made possible by new, more reliable and precise actuators.

Figure 17 - Precision Farming concept

Using information from various sources, implemented by heterogeneous resources within the farm (the information collected by a combine of a given brand can be used when using a sprayer of another brand), precision agriculture can only progress through research on systems interoperability.

Sensors and remote sensing

Improvements in sensors help to bring even more precise information on soil parameters such as humidity, on the state of cultivation (development stage, water resource stress, deficiency, crop disease...) and on operation of the machine. These sensors can be located on the plot in the soil, placed on the machine (proprioceptive sensors to know the status of the machine and exteroceptive for crop or environmental conditions) or placed on other carriers (sensors carried by drones or satellites), they can also be placed remotely, for example weather measuring stations or rain radars.
Research in the field is heading in the direction of miniaturization, controlling the use of energy (especially important in the case of wireless sensor networks where sensors located on plots are not connected to an external power source).

The on-board cameras have been miniaturized and their resolution and brightness significantly increased. Multispectral or optical, they provide images that can then be analyzed and used for the detection of diseases, weeds or deficiencies.
The emergence of new measurement capabilities (e.g. using the near infrared spectroscopy and chemometrics) gives new possibilities for remote sensing [24].
The development of wireless sensor networks (WSN), the improvement of the robustness and energy frugality of these networks are promising solutions for the instrumentation of farms [16]. Data collected with WSN can then be integrated and stored in data warehouses from which, combined with other data (e.g. from machines), they can be exploited using decision support systems, which are in turn becoming more and more efficient and relevant [9].
Based initially on satellite detection, where the precision and richness of information continue to grow, precision agriculture now benefits from the development of UAVs carrying multispectral sensors that perform on request prescription maps for fertilization.

Location

The progress of tracking systems and improvements to their accuracy with DGPS and RTK systems allowed the development of precision agriculture. The centimeter accuracy offered by the RTK system meets most of the needs of precision agriculture. It is however necessary to ensure the reliability of information and take into consideration where the antenna of the GPS receiver is located. For applications requiring high accuracy the geometry of the machine and of the landform must be taken into account. So corrections are needed. Modeling the behavior of the machine, use of proprioceptive sensors such as accelerometers or inertial sensors can help make those corrections. For instance a yield map will be issued by taking into account as far as possible the precise place where the crop has been harvested (for instance the cutting bar of a combine), independently of the method used to calculate the yield (and the location in the machine of the sensors used for this calculation). In the same way, for precise spraying it is necessary to locate the sprays of the different nozzles of the sprayer.

Geographic Information Systems (GIS)

Combining soil mapping, yield maps and information concerning the crops, combining data from remote sensing (satellite and drones) and adding, to the spatial dimension, the time dimension that is essential when looking at agri-environmental data, geographic information systems are becoming increasingly complete. The improvements to GIS are obtained thanks to the increase in the number of layers (type of information which can be stored) and their resolution. They are then able to provide information which, thanks to a decision support system, allows the machine to take appropriate action, controlledeither by the operator or automatically.

Decision Support Systems (DSS)

Processing an increasing number of data, these decision support systems are all the more useful when the amount of information to be processed is significant, and therefore the decision most difficult to develop.

These systems need to be configured by the user depending on the level of risk (economic, environmental, agronomic) he agrees to take. This is therefore not a black box whose operation escapes the farmer, but a tool helping him to drive its practices based on the choices he makes. The efficiency of the DSS is improved by the relevance of the models they are based on (growth patterns of plants, disease models, etc.). Thanks to Internet it is possible to connect the DSS to knowledge information management systems, and thus greatly increase the performance of the DSS.

Variable Rate Technology (VRT)

With precision farming a new paradigm is implemented. Indeed, in the late twentieth century improved machinery was made, tending towards the best possible regularity whether for the distribution of pesticides by boom and air-assisted sprayers, or for the distribution of fertilizers by centrifugal fertilizer spreader, or manure spreaders and slurry tankers. All environmental standards were in effect in this sense,s demanding machines that apply, as regularly as possible, the nearest dose possible to that chosen by the operator. With precision farming it is now necessary to adjust distribution in the finest possible manner, according to the needs of the crop or the plot. For the application of pesticides, different devices are available: boom sections control flow regulation nozzle by nozzle, while ensuring that a constant distance is maintained between the boom and the soil, or other more specific solutions ensure that only the target is reached by the applied molecules. Some centrifugal fertilizer spreaders are now designed in such a way that they adapt the spreading pattern to the limits of the plot and the needs of the crop.

Interoperability

Precision agriculture has been developed thanks to the improvement of the interoperability between tractors and machines and between machines themselves. The keystone of this interoperability is the ISOBUS. This project was born in the early 1990s, it was initially to facilitate communication between the machines and define the format of a "Universal Terminal." The work that mobilized industries and universities has relied on the SAE-J1939 standard. This standard was primarily dedicated to closed systems such as tractors or self-propelled machines bus and the challenge was to extent the concept to open systems, enabling communication between tractors and machines of various brands. The different parts of the ISO 11783 enabled great progress, even if their implementation still calls for research to move towards greater interoperability, simplicity and compatibility [58]. Another means of interoperability is now offered by Internet of Things (IoT) [31]. This is a very promising way.

Man-Machine Interface (MMI)

With the advent of precision farming, each manufacturer developed its own control and visualization system. Soon the tractor cabs of the most innovative farmers became cluttered with multiple displays and control panels. Development of ISOBUS and ergonomic research has simplified the control and information systems. The tractor driver is able to control machines from the cab in a more simple and intuitive manner. In the same way he is informed of the work of his machine through feedback given by the display. MMI will still continue to improve, using virtual reality or head-up display for instance [34].

Precision Livestock Farming (PLF)

While the precision settles in crop production, animal husbandry has also been using new technologies for many years. PLF aims to create a management system based on monitoring and permanent control in real-time of the production / reproduction, health and welfare of animals and the environmental impact of production [5]. Works on precision livestock farming were initially interested in guarding animals without a fence or controlling the atmosphere in livestock buildings. A big step forward was made in the 1990s with the appearance of the milking robot. This has resulted in improved welfare for the farmer, who is no longer forced to be present during milking. Milking robots also improve the welfare of animals, which can be milked at their convenience. With milking robots, the animal itself is tagged so as to be recognized during milking and receive its individual ration, calculated considering its production and needs. The development of RFID technology helped facilitate and make more reliable the detection of animals. The biosensors can anticipate the onset of disease. The coupling of the animal identification, tracking their path through an integrated GPS chip and a geographic information system implementing the principles of precision livestock farming, for extensive farming, makes it possible, for example, to control the development of animal disease and treat only animals which have a high probability of having come into contact with an infected animal, rather than treating a whole herd.

Scientific and technological developments make it possible to pass from comprehensive treatment at herd level to differential treatment tailored to each individual in a herd. This improves overall performance by limiting the use of veterinary products to the essential, and feeding each animal with the necessary ration.

From Precision Agriculture to Autonomous Machines

Progress in the field of localization, through the development of GPS and correcting systems with a high level of accuracy, the development of new sensors and the increasing power of computing embeddable in machinery opened the way for the development of robotics. In 1990 Jean Lucas announced to the Club of Bologna that the coming period in agriculture would be *the "robot herds" period* [37]. Since then, many advances have been made, but the robot fleets have not invaded the country [42]. As we have seen above, the milking robot has grown significantly: in 2012 nearly 13,000 dairy farms worldwide were equipped with milking robots.

However, the development of mobile robotics has a number of technical and scientific brakes. There are a lot of issues that must be resolved so that robotics can be generally used in agriculture, for instance: the machine integrity and ability to maintain its planned trajectory whatever the circumstances, machinery autonomy to react appropriately in the presence of an unforeseen event (obstacle or operating incident), tools control (combination of mobility of a platform and path accuracy of a gripper arm for a fruit harvesting machine, for example), environmental characterization within which the machine operates, digital terrain model design, cooperation

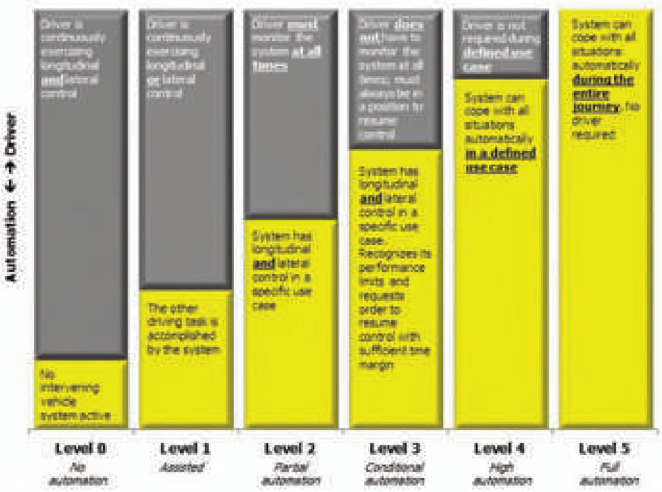

Figure 18 - Levels of driving automation *[Source: SAE J3016]*

between different machines, ability to localize, including sheltered areas where GPS signals are not received. Between machines entirely controlled by man and fully autonomous machines, intermediate steps demonstrate the new capabilities offered by robotics. The level of autonomy can be described as for automotive vehicles (**Figure 18**). Some manufacturers offer advanced automations such as automatic guidance control or auto turn on headlands. The scientific and technical works of recent years have allowed the marketing of feeding robots and weeding robots for example. More and more manufacturers present prototypes of robots during international exhibitions (cooperation between a driven tractor and an autonomous tractor, or fully automated coupling of a trailed implement and a power take-off to a tractor, for example).

Cooperation between land and aerial robots opens up very interesting prospects in agriculture[1] (**Figure 19**). It provides the possibility to acquire images of the task field to improve guidance of the ground robot, to avoid obstacles and to re-plan the mission if necessary.

Figure 19 - UAV used for weeds control (RHEA Project) *[Source: Labbe S. Irstea]*

Figure 20 - Research into autonomous cooperative platforms *[Source: Benet B. Irstea]*

1 See «RHEA project» http://www.rhea-project.eu

The cooperation between man and robots will also develop; cobotics (*collaborative robotics*) is supposed to change the face of manufacturing in the next few decades. In agriculture, "follower robots" for wine harvesting, for example, appear on the market. Exoskeletons that are emerging in the industry could be a solution for improving working conditions for operators employed in heavy labor, high value but difficult to automate.

Questions arise as to the future of robotics in agriculture (**Figure 20**): will it give more autonomy to existing machines (by automation of tractors, combine harvesters and so on), or will it find expression in a real breakthrough? The authors are divided on this. Some plan ever more powerful machines (but with a similar design to the current ones) that are wider and faster and can work larger and larger areas in a short time. Others believe it should instead use multiple small autonomous machines able to work 24 hours a day, causing no soil compaction, achieving finer, more accurate work than the larger ones and consuming less energy because of their lower forward speed.

The development of robotics raises the question of the safety of people (farmers, bystanders) in the vicinity of the autonomous machines. This question, which has regulatory and normative extensions, is dealt with by

Figure 21 - Example of Connected Farm *[Source: ANDRE G. Irstea]*

implementation of the most reliable methods of programming, and development of qualification procedures (or certification of autonomous machinery) that take into account interactions between people (farmers and bystanders) and autonomous machines, with a special attention for the man machine interfaces.

Big data

Precision farming and robotics, due of the number of sensors they use, are producing a great number of data. They also need a great number of data they do not produce themselves. They are part of "*connected agriculture*" where a large amount of data coming from farms, co-operatives, service-providers has to be managed and shared. Those data can then be used for the improvement of Decision Support Systems and become part of Management Information Systems [50] (**Figure 21**). That means that research activity in the area of big data has a positive impact on precision farming.

It is not possible to conclude this chapter on precision farming without mentioning the various obstacles to its spread, despite the proven benefits it brings to farmers and to Society in general. Development of agriculture will build on the contributions of the scientific and technological developments mentioned above. It needs an improvement in the reliability and cost reduction of the implemented technologies, with easier access to data. As has been more and more recommended, living labs and open innovation methods have to be implemented to promote dissemination of Precision Farming. New training curricula for the different players in the agricultural sector (consultants, industry, supply chain, service providers, extension services and finally the farmers themselves) need to be issued. These topics have to be addressed by research in the coming years [19].

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CHAPTER 4

AGRICULTURAL MECHANIZATION IN THE UNITED STATES OF AMERICA

CHAPTER 4 AGRICULTURAL MECHANIZATION IN THE UNITED STATES OF AMERICA

BY **JOHN K. SCHUELLER** (USA)

INTRODUCTION

Agricultural mechanization has been very important to the United States of America (USA) over its history. The country was formed and expanded by settler colonialism where immigrants from abroad settled the Atlantic shoreline and pushed westward, replacing the native populations. Perhaps largely due to the interactions of diseases from the European, African, and American continents reducing the populations, there was often ample land for agriculture, but a shortage of labor. As the industrial revolution and service economies later took hold, there continued to be a need for labor to be productive. Hence, the economic and social conditions were generally very supportive of mechanized agriculture. Because of this high demand for mechanization, many of the agricultural mechanization technologies used worldwide were first developed or popularized in the USA [2]. The high productivity of USA agriculture, greatly aided by the widespread use of innovative agricultural equipment, contributed to the development of a strong country. Agricultural mechanization has been identified by various organizations as one of the top engineering achievements of the 20th century [4].

Even the founders of the USA were interested in agricultural equipment and mechanization. For example, Thomas Jefferson (the writer of the Declaration of Independence and the third president) used mathematics to design a more efficient moldboard plow. There was widespread interest in developing improved agricultural equipment throughout the nineteenth and twentieth centuries. Early efforts resulted in advancements in the technologies of the reaper, thresher, self-scouring plow, and other equipment. Innovators and industry leaders included such well-known individuals as Cyrus McCormick, J.I. Case, John Deere, and Henry Ford. As agriculture spread westward, innovative equipment made widespread productive agriculture possible and the development of such major agricultural areas as the corn belt, wheat belt, and California Central Valley. However, the development and popularization of mechanization took time. Even as late as 1910 the value of horses and mules on USA farms exceeded the value of all farm machines and equipment. Eventually the USA grew to producing substantial portions of the world's supply of certain agricultural commodities, such as corn and beef, with a highly mechanized agriculture.

The USA is the world's largest country with an area of almost ten million square kilometers. There is a great variety of climates, topographies, soils, and sociopolitical differences within the country. Hence, it is very difficult to make generalizations about the agriculture and agricultural mechanization. Also, mechanization varied according to the commodity. For example, wheat was mechanized very early, but sugar cane was not fully mechanized until recently.

Agricultural mechanization in the USA is a very complex subject which can be studied in many different ways. To give some order to this subject, the topic here will be divided into major categories of agricultural operation and equipment types. Unfortunately, only examples of the most significant types that are used for the production of the most popular agricultural commodities can be discussed.

AGRICULTURE IN THE USA

USA agriculture varies widely in climates, crops, cultural practices, field and farm sizes, topographies, and social organizations. **Figures 1, 2, 3, 4** and **5** map example variations in crops and cultural practices while **Figures 6, 7**, and **8** show ownership and size variability. USA farm owners and operators are diverse and generally fiercely independent. They have different heritages, often based upon their ancestors' countries of origin, and are often able to maintain those heritages because they live in communities of similar ancestries far from population centers. Although these differences were reduced some with the much greater mobility after World War II, they still do exist to some degree. USA farms often have quite sophisticated workshops and therefore there is much local agricultural mechanization experimentation which also leads to more local mechanization variability. Due to this diversity, the general statements made here must be viewed as having been made with a broad disclaimer.

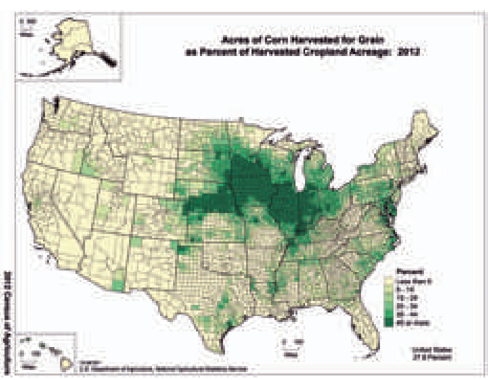

Figure 1 - Percentage of cropland in corn (Maize)

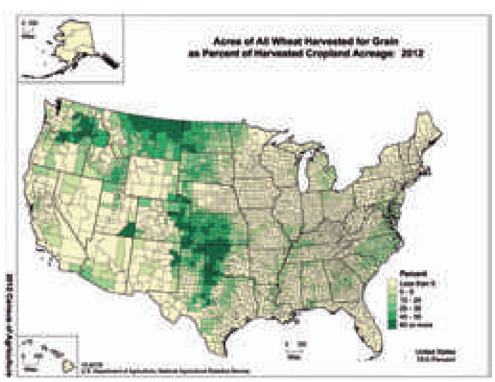

Figure 2 - Percentage of cropland in wheat

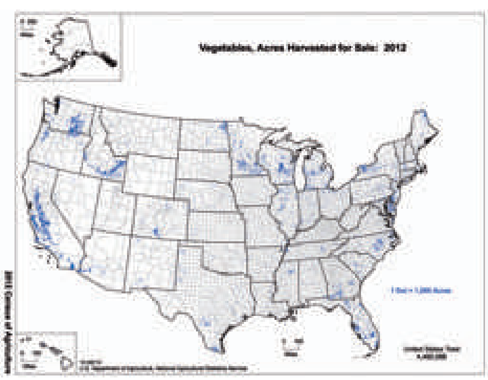

Figure 3 - Cropland producing vegetables

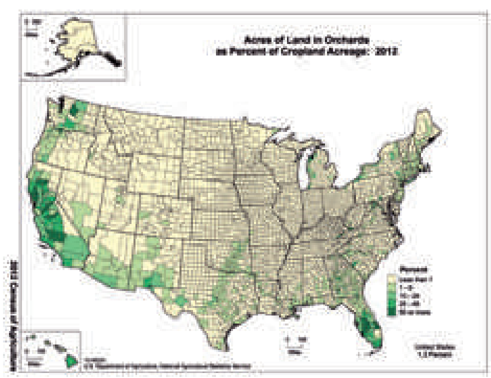

Figure 4 - Percentage of cropland in orchards

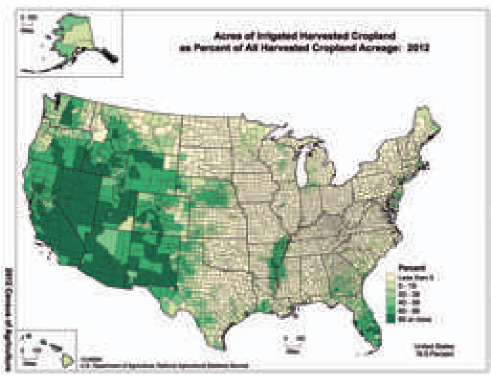

Figure 5 - Percentage of cropland irrigated

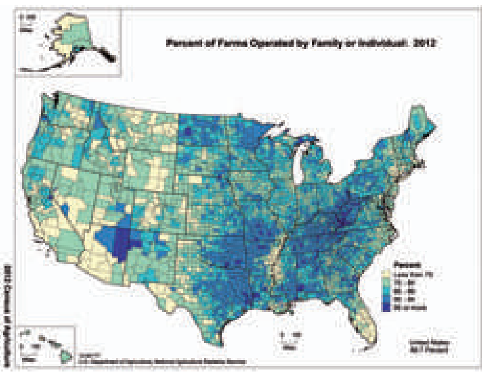

Figure 6 - Percentage of farms owned by individual or family

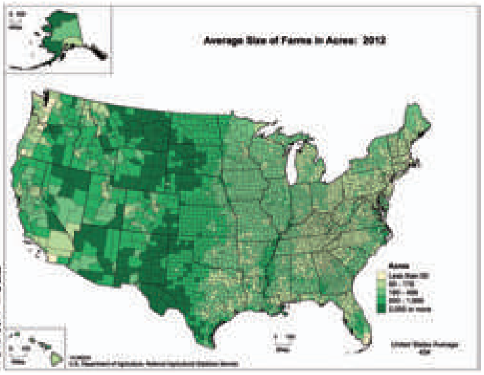

Figure 7 - Average farm size (1 acre = 0.4 hectare)

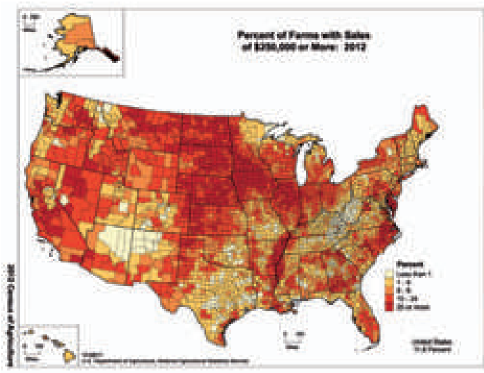

Figure 8 - Percentage of farms with more than US$ 250,000 sales

The European settlers initially settled on the eastern Atlantic coast. Initially the farms were not specialized and each produced a wide variety of crops and animal products. Although there has now been substantial consolidation over recent centuries, the farms in this region tend to be smaller than in other regions, often due to history, topography, and other geographic influences. In the northern part the production tends to be more dairy and temperate fruits and vegetables. This, combined with the smaller field and farm sizes, means there is a trend towards smaller tractors, haying and forage equipment, and smaller equipment in general. The more southern states have coastal plains which allow larger farms and larger equipment. Grain crops are grown along with crops such as cotton and peanuts.

As the country developed, agriculture moved westward. Mechanization was very important to this development, as items such as the self-scouring plow and the reaper allowed large areas to be farmed with limited labor. These areas tend to have larger farms and larger equipment. Most farms are family-owned, even most of the larger ones.

The "upper-Midwest", including such states as Michigan, Wisconsin, and Minnesota, has dairy and temperate fruit and vegetable farms, with many acres (one acre is 0.4 hectare) of corn and (now) soybeans. They use traditional tractors of moderate size.

The "corn belt" of Indiana, Illinois, Iowa, and large portions of neighboring states, has mainly a corn-soybean rotation. The primary mechanization here is medium-to-large tractors (most with larger rear wheels) with relatively large tillage, planting, and crop protection equipment. Large grain combines are used. Fertilizing and crop protection may be done by the farmers with their equipment or by custom applicators with large equipment. As this area of the USA is large and productive and many of the equipment manufacturers are located here, this area has a large influence on the equipment industry.

Further west and north is the wheat belt due to lower rain and, in parts, cooler temperatures. Many farms are very big with large articulated equal-sized four-wheel drive tractors. The equipment is sized accordingly. Where there is even less rainfall there is rangeland used for grazing and only limited equipment to support the rangeland and livestock.

The southern part of the USA has a warmer climate and also includes crops, such as cotton, rice, and peanuts, which can thrive in that area. The equipment tends to be of medium to large sizes depending upon the local situation. There is a tendency to more hired employees operating equipment.

The "Fruitful Rim" exists around the south and west sides of the USA near the oceans. This region includes many fruit and vegetable farms, some quite large. The establishment and protection of these crops is mechanized. Generally, the harvest of crops for processing, such as freezing, canning, or juice-making, is mechanized. However, the harvest of much of the fruit and some of the vegetables harvested for fresh market sales is still not mechanized. There is much research for such mechanization, but it is hurt by the diversity of commodities and the small potential equipment sales markets for any single commodity. This lack of mechanization has contributed to the extensive importation of these commodities from lower-labor-cost countries.

There are fifty states in the United States. But even in single states, especially the large states such as California, Texas, and Florida, there is much diversity. For example, Florida has substantial production of commodities as diverse as citrus, beef, sugarcane, tomatoes, dairy, blueberries, corn, avocados, and potatoes. So this causes a great variety of agricultural mechanization.

TRACTORS

As in most other countries, having a separate chapter in this book shows that the most important type of agricultural equipment in the USA was the tractor. Its ancestors were the large steam engines used to provide power for stationary operations. The steam engines provided power for threshing machines and other equipment about a hundred years ago. Initially towed by horses, they eventually became self-propelled tractors to move from farm-to-farm and to provide towing power themselves for tillage operations.

But tractors did not achieve truly widespread usage until internal combustion engines were sufficiently developed and applied to tractors. There were very many tractor companies and many different designs in the early days. Less successful companies and designs gradually disappeared as the best technologies in tractors discovered and refined. Williams [6] provides an excellent history of these and later tractor developments in the USA.

One of the most important steps in the popularization of tractors was the Fordson tractor marketed starting in the latter part of World War I by Henry Ford. The success of the Farmall tractor by International Harvester allowed the row-crop farmer, especially in the corn belt area, to use a tractor for a variety of field operations. The handshake agreement between Henry Ford and Harry S. Ferguson regarding the three-point hitch system contributed to the USA's peak manufacturing of tractors when over 100,000 Ford model 8N tractors were produced annually after World War II. These and other developments led to the gradual tractorization of all of USA agriculture. Common tractor size and power significantly increased in the 1960's with the John Deere New Generation tractors (such as the 4010 and following 4020 models) and their competitors. Since then there have been significant evolutionary changes, such as the continuing trend to higher power and the increasing popularity of four-wheel-drive and cabs.

While the earliest tractors used wood and coal, liquid fuels have been used through most of the history of tractors in the USA. Early in the twentieth century kerosene was popular. But it was soon superseded by gasoline, which remained popular until diesel became dominant late in the century. As time passed, more and more diesel engines became turbocharged. Although some older tractors still in use are fueled with gasoline, most tractors now are diesel. Through much engineering effort, the fuel efficiencies and emissions of tractors have continued to improve. Current tractors produce as much as 19 HP-hours per gallon (3.7 kW-hours per liter) of diesel fuel. All tractors being sold must meet U.S. Environmental Protection Agency (EPA) Tier 4 standards, which have strict requirements for carbon monoxide, hydrocarbons, nitrogen oxides, and particulate matter emissions. To meet these requirements, contemporary engines not only are well-designed and electronically controlled, but they utilize such technologies as selective catalytic reduction (SCR), exhaust gas recirculation (EGR), and diesel particulate filters (DPF).

Because tractor drive wheels turn at a very slow rate compared to engine speeds and the needed speeds vary greatly depending upon the particular agricultural operation, transmissions are very important for tractors in the USA. Tractors primarily used gear transmissions. The number of transmission ratios in a tractor's transmission increased over time. Clutchless shifts, either a "powershift" transmission which required no clutching or a "range" transmission where clutching was not required within groups of ratios gradually became more popular, especially in the 1960's. Various versions of these transmissions still are popular. Continuously-variable transmissions are successfully marketed in the USA at this time and are increasing market share, although adoption appears to be behind Western Europe.

Given the wide variety of farming operations and the sizes, commodities, and management strategies involved, the tractor structures vary. But most USA tractors are of the standard designs used in most of the world. The tractors of most interest are the "row crop" tractors of approximately 100 to 300 horsepower, used by most medium and large USA farms. These tractors have Ackermann (car-like) steering, with the front wheels smaller than the back wheels. Smaller farms use more "utility" tractors, which are similar in design, though generally lower in height and in the horsepower range of perhaps 40 to 100 horsepower. The largest farms, especially where row crops will not be damaged, use large articulated tractors of about 300 to 600 horsepower. Although a few tractors were steel-tracked during the twentieth century, most tractors used wheels. Late in the century, rubber tracks were popularized. Rubber tracks have been achieving increasing market share in the larger tractors, but wheels still dominate.

Hydraulics are a very important part of agricultural tractors due to their ability to supply high forces and powers. Hydraulic capacity has significantly increased as time passes to meet the needs of air seeders and other equipment. The general trend, depending upon manufacturer and tractor size, has been to move from open-center to pressure-compensated to load-sensing systems.

The electronics on tractors developed similarly to how the electronics developed in other automotive industries. Originally "islands of automation", the various electronic systems are now being networked together using SAE J1939 and ISO 11783. Automated guidance using GPS has recently become popular.

Given the size of the USA, it is a very large tractor market. Hence, there is production, import, and export of sizable numbers by both domestic and international companies. In 2015, there were sales of 118,348 tractors of less than 40 horsepower, 59,401 tractors of between 40 and 100 horsepower, and 23,930 tractors of over 100 horsepower in the USA [1]. This does not include tractors with all four wheels being the same size, of which 3,111 were sold. Some tractors, especially in the smallest category, are utilized in industries other than agriculture. These sales represented a decline in all categories above 40 horsepower from the 2014 sales, and current 2016 sales have declined further. USA tractor and equipment sales are greatly affected by agricultural commodity prices, economic conditions, and seasonality, and therefore can vary widely. A total of between 10,000 and 25,000 tractors and self-propelled combines are sold each month. The current distribution of tractors on agricultural operations is shown in **Figure 9**.

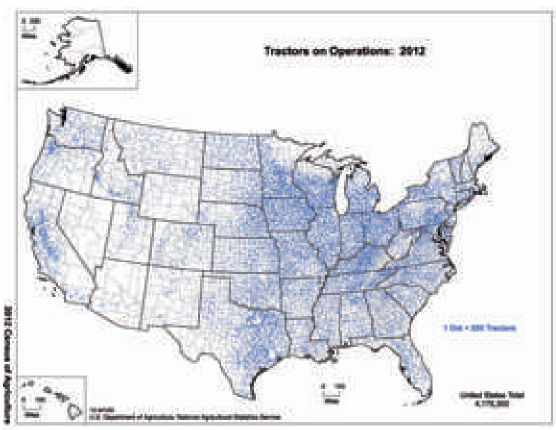

Figure 9 - Tractors in use in agriculture

It is always hazardous to predict the future. But it is expected that the current trends will continue to a large degree. This means increasing numbers of CVT's, increasing use of rubber tracks (although still a minority), and increasing power and efficiencies of hydraulics. There will be substantially more use of electricity to power auxiliary drives (air conditioning, engine cooling fans, some implement functions, etc.).

There will be much greater automation of tractor operation. The common tractor of the future will be programmed to follow the paths, and will have travel and operation speeds which optimize the field operations from the standpoint of agronomic or horticultural economics. Within those parameters, the engine, transmission, and engine auxiliaries will operate at optimal points. Coordination with other equipment and implements will be improved.

The most substantial changes in the near-term will be improved information handling. More information will be provided to the manufacturer, the operator, and the farm manager. This will be information on operation of the tractor, operation of the implements and attachments, and the soil and crop characteristics.

TILLAGE

For much of the USA's history, the moldboard plow dominated tillage. As mentioned above, the moldboard plow was very important for opening the corn belt and other areas. But use has declined to the point that most farmers do not have a moldboard plow. Primary tillage is conducted with other tools, such as chisel plows, disks, and rippers. Secondary tillage includes the use of field cultivators, disks, harrows, and various finishing tools.

Many fields, especially grains and soybeans, are farmed with no-till, minimum tillage, and conservation tillage methods. These methods are heavily promoted to the farmers as environmentally responsible to reduce water and wind soil erosion. They are also felt to consume less fuel and time and require less equipment investment.

No-till is popular in some regions, particularly in corn/soybean rotations and in small grains. There is no tillage and hence no need for tillage operations or equipment. However, its usage changes the required planter mechanization, and weed control has to be supported by effective herbicide application.

Minimum tillage and other forms of conservation tillage leave substantial crop residue on the soil surface to protect against erosion, and their characteristics are generally somewhere between no-till and conventional tillage which begins with moldboard plowing. With the popularization of accurate automatic guidance using GPS, strip tillage has started to become popular. It combines the advantages of conventional tillage in the crop row with no-till between the rows. It is likely that its use will continue to increase.

Farmers growing vegetables and other specialty crops often want very clean soil surfaces and smooth planting conditions. So they generally perform more, and more intensive, tillage operations. Some use powered rotary tillers, although their use appears to be much less than in Western Europe.

The contemporary tillage equipment used in the USA will often include a variety of soil-engaging elements. For example, chisel points, disks, and rolling baskets might be included on the same implement. It is also common to perform multiple field operations in a single field pass behind a single tractor, for example tillage, fertilization, pesticide application, and planting. This combining of operations increases productivity and reduces labor needs. It can also contribute to timeliness. Timeliness in planting operations is very crucial in many USA situations and therefore tillage productivity and timeliness are also crucial.

CROP ESTABLISHMENT

Most crops in the USA are established from seed. Row planters are used for such crops as corn, cotton, and most soybeans and vegetables. Due to the critical nature of planting, there has been much experimentation and development in planting equipment. Row spacing varies, but has tended to decrease. There has been much work on opening and closing the trench where the seeds are planted. This is especially critical now that conventional tillage is less popular. The various conservation tillage and no-till production systems require planters that can plant accurately into residue and untilled soil. Seed metering and placement has been another area of development. Plateless planting replaced the use of plates in the late twentieth century. Automatic control of plant population has also become popular. Some precision agriculture promoters have advocated planting multiple varieties with multiple seedboxes on planters, but this has not yet become popular.

Wheat and other small grains are broadcast seeded. Large air seeders are often used to plant these crops. Again, the seeders have to operate in less-tilled soil and more residue. Some vegetable are transplanted.

The trend of planters is more precise placement and significantly faster planting speeds. The seed or transplant is to be put at the proper depth with very uniform in-row spacing with no doubles or skips. With the advances in precision agriculture, the future may see the exact location of every plant being known and controlled. The planting and progress of individual plants will be stored in databases.

CROP PROMOTION AND PROTECTION

The promotion and protection of crops through the application of items such as fertilizers and pesticides is highly mechanized. These items can be applied before, during, or after planting. If applied during planting, the application equipment can be part of the planting equipment or can be one of multiple pieces of equipment pulled by the same tractor.

Of course, most pesticides are applied during the crop growth. Nutrients can also be applied during crop growth. One common USA example which seems less common in other countries is the knifing of anhydrous ammonia into the soil between the growing rows of corn.

Although application operations are often performed by farmers, especially larger farmers, application operations are often done by the supplier of the fertilizer or pesticide. Because such suppliers have many customers, they often operate very large machines at fast travel speeds, even on small farms.

With the advent of precision agriculture, there was much research, development, and commercialization of variable application rates [3]. The idea is to only apply the fertilizer or pesticide where it is needed. This makes economic and environmental sense. Such variable rate application is now widely available. Although it is still only used on a minority of the cropland, its use is increasing.

The various applicators are generally now automated. Automated GPS guidance and individual nozzle shutoffs minimize skips and overlaps. Automatic controls ensure that the desired rate is applied. There has also been substantial effort on placing the inputs in the proper positions relative to the plants. Much ongoing research and development is working towards the goal of being able to apply the right amount of the right fertilizer or pesticide at the right place at the right time. For example, it is likely that eventually machine vision systems will be developed to find weeds and the resulting applicators will apply the correct amount of pesticide to each individual weed.

Mechanical weed control was important through most of the USA's history. While implements such as cultivators and rotary hoes are still used in the USA, their importance has declined due to the widespread use of effective herbicides. But there is now renewed interest due to the greater production of organic crops, increasing restrictions on herbicides, and increasing herbicide resistance among weeds. Improved robotic technologies may aid the resurgence of mechanical weed control.

HARVESTING

Harvesting is, of course, very crucial for most crops. It is where the product is acquired and the quality is maintained. Other than some fresh market specialty crops such as fruits and vegetables, most USA harvesting is mechanized.

Harvesting of grain and related crops was mechanized very early and continued refinements have reduced losses substantially. Major developments during this process were the reaper, threshing machine, and combine. On the many large and medium-sized farms which have grain, soybeans, or other crops which can be combined, the self-propelled combines are the most sophisticated and costly pieces of agricultural equipment. Custom harvesters generally harvest the remaining fields of such crops. Combines in the USA are large and self-propelled. They may be of either conventional or rotary designs, with rotary designs moving towards market domination. Contemporary combines incorporate sophisticated electronics. In 2015, 5381 new combines were sold in the USA, also less than in 2014 [1]. The distribution of combines for grains and beans (not including for other crops) is shown in **Figure 10**.

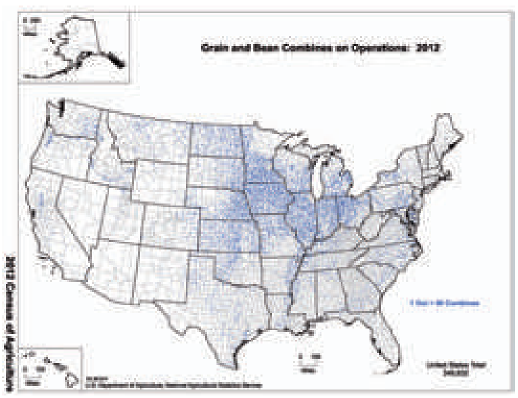

Figure 10 - Grain and bean combines in use

In the 20th century, hay and forage crops were traditionally harvested in a series of operations which included a mower, rake, and chopper or baler, all pulled by tractors. The crop is now cut with self-propelled windrowers. Dried hay can be baled by small square balers, large square balers, or large round balers. The large round balers developed in the late twentieth century are now very popular. If chopping is done, large self-propelled forage harvesters are often used. Forage crops are harvested and stored at different moisture contents depending upon local conditions and animal feeding preferences.

Cotton harvesting was not substantially mechanized until after World War II. Either cotton pickers or cotton strippers are used depending upon local conditions. Module builders in the late twentieth century compressed the harvested cotton into modules at the ends of fields to reduce the bulkiness of the harvested cotton before transport. But now smaller modules are compressed and formed on the self-propelled harvesters themselves.

Although the mechanization to harvest major crops is quite similar throughout the USA, and usually may only vary in the predominant sizes at different locations, the mechanization of specialty crop harvesting is quite variable. Sugar cane uses self-propelled billet harvesters, while many peanut combines are pulled by tractors. Tree nut crops tend to use shaking equipment, but fruit trees are mainly harvested manually. Some vegetables such as green peas, green beans, and sweet corn have sophisticated complete mechanization, but others, especially for fresh markets, are harvested without mechanization.

There is interest and very much research and development to try to mechanize those crops that are still harvested without mechanization. There are efforts to develop both mass harvesters which harvest from entire plants or trees at one time and robotic harvesters which will harvest individual fruit on a plant. In cases where the selection and detachment is very difficult to mechanize, there are also attempts to develop mechanized harvest aids which will place the human workers in the proper harvesting position and/or handle the harvested fruit.

Yield mapping during harvest has been an area of recent development and has had uneven adoption by farmers. It is likely that yield mapping will continue to expand, both among farmers and to commodities beyond its current main use in grain combines. Automatic quality property measurement and mapping of the harvested crops will also continue to expand, as will automatic controls, including adaptive control of the harvesting machines.

TRANSPORT

The increased productivity of the agricultural equipment which performs the planting, fertilizer and pesticide application, and harvesting operations has caused materials handling often to be a bottleneck in many agricultural operations. Vast quantities of seeds, fertilizers, and pesticides must be transported to the fields and loaded into the planting and application machinery. At the end of the season, high-yielding crops mean that large amounts of harvested crops must be removed from the fields.

Historically, tractor-pulled wagons dominated. They are still extensively used. Special designs for particular operations, such as planter tenders, forage wagons, and grain carts have evolved and are widely used. The good road system in the USA has also allowed large trucks to be widely used. Some anticipate that transport of agricultural materials will be one of the first widespread applications of autonomous vehicles in the USA. However, that has not occurred yet.

FUTURE TRENDS

The above sections indicate the historical and current trends. **Figures 11** and **12** show the market value of agricultural machinery on farms. The trends are expected to continue.

The use of electronic and information technologies will expand, with a movement towards obtaining maximum quantity and quality from each plant with minimum economic investments and environmental im-

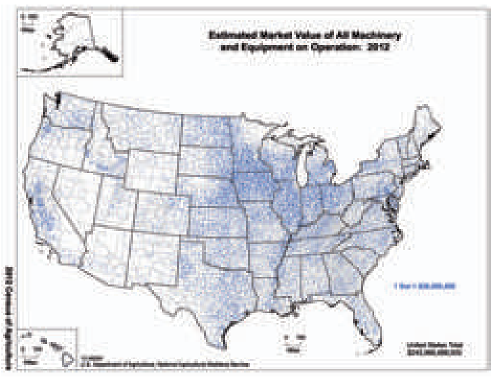

Figure 11 - Market value of machinery and equipment

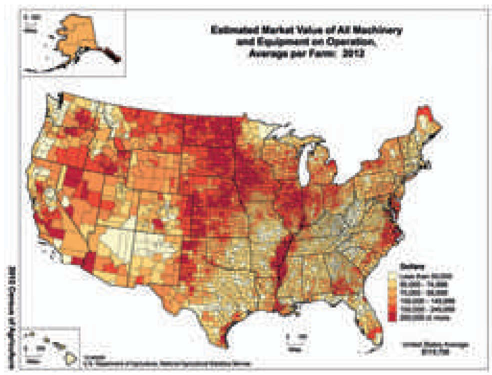

Figure 12 - Market value of machinery per farm

pacts. Much of the improvement will be due to more and improved sensors, which will more accurately determine the characteristics of soils, crops, and pests, even in complicated physical, chemical, and biological agricultural production systems.

Unmanned aerial vehicles are now starting to fly over fields to perform scouting and other operations. If autonomous agricultural equipment becomes popular for any of the field operations discussed above, it could be disruptive to the types and designs of USA mechanization equipment. For example, if labor is not required to operate the autonomous equipment, multiples of smaller equipment might replace the current large single pieces of equipment to reduce soil compaction and improve reliability through redundancy. However, whatever system evolves it must be productive in quickly handling large areas and the considerable inputs and crop yields found in USA agriculture.

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CHAPTER 5

AGRICULTURAL MECHANIZATION IN LATIN AMERICA

CHAPTER 5
AGRICULTURAL MECHANIZATION IN LATIN AMERICA

BY **ETTORE GASPARETTO** (ITALY), **LUIS MÁRQUEZ** (SPAIN)

SOCIAL AND ECONOMIC EVOLUTION OF AGRICULTURE

The Latin American and Caribbean region includes numerous countries; among them there are small island states and big countries with important economies at world level [6].

The region is full of many natural resources and, generally speaking, presented a big economic increase during recent decades. On the other hand, 47 million people are not sufficiently fed; the majority of this population lives in rural zones and depends on subsistence agriculture.

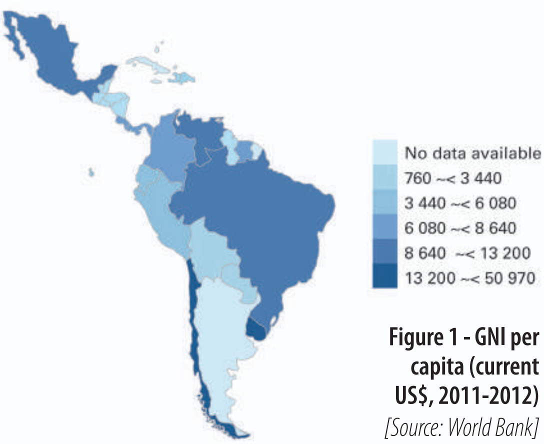

Figure 1 - GNI per capita (current US$, 2011-2012)
[Source: World Bank]

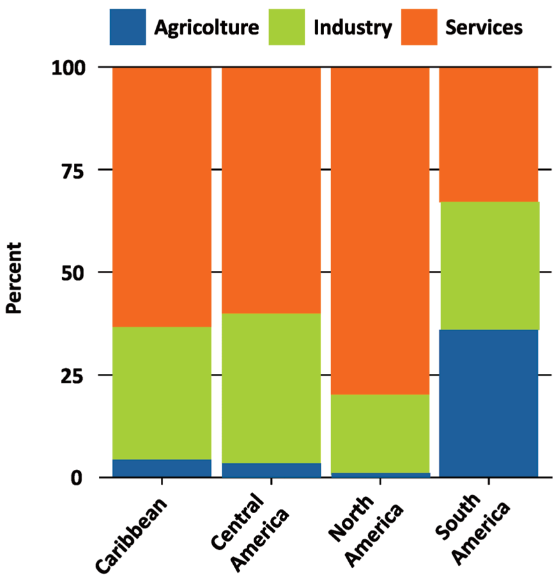

Figure 2 - Value added in agriculture, industry, and services as share of GDP (2011)
[Source: World Bank (WDI)]

Population and GDP

It is estimated that the Latin American and Caribbean population amounts to 597.7 million people (2012) and this corresponds approximately to the 7% of world population. Its rate of growth in the last decade of the Twentieth century was equal to 1.7%, while in the first 15 years of the Twenty-first century this reduced to 1.3%. It is expected that in the next 15 years the population growth rate will be 0.9%, similar to the one estimated at world level.

As in all the world, the population becomes more urbanized every year; it is estimated that the rural population in 2015 was reduced to 115 million people, with a selective emigration where young people are predominant. The island states are the most rural. The South American population is almost as urbanized as that of North America, and significantly more urbanized than the world average. At the limit Argentina and Uruguay have only a low 7.5% of rural population.

The region GDP per capita in 2012 increased by two times that of the year 2000, in spite of the 2008 financial crisis. Nevertheless, it is estimated that in 2010 one third of the population was devastated by poverty and, of course, the highest poverty levels occur in the rural zones (**Figure 1**).

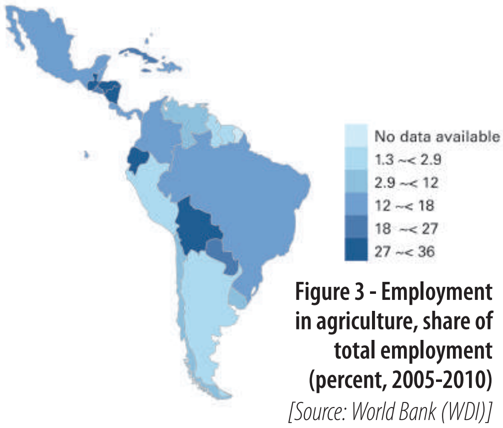

Figure 3 - Employment in agriculture, share of total employment (percent, 2005-2010)
[Source: World Bank (WDI)]

The region recovered well after the economic crisis. Although in the year 2000 there was a deceleration that intensified in 2015 in a country as large as Brazil. The agricultural added value represents more than 6% of GDP, much higher if compared to the world 2.7% average. Big oscillations are recorded as a consequence of the periodic draughts in the Southern Cone of the continent (**Figure 2**).
In Latin America and the Caribbean the percentage of agricultural active population is a little less than 15%, with a considerable variation within the region (more than 30% in Central American countries and Bolivia, and only 1.3% in Argentina). The percentage of women employed in agriculture is equal to 9.1%, much less than the average for developing countries (43%) (**Figure 3**).

Agricultural area and water

Agricultural production has increased in the region, although the surface employed in agriculture did not record a significant variation. 37% of total land is utilized for agriculture and 47% is covered with woodland. 2.7% of the agricultural surface in the region is occupied by permanent crops and 75% by prairies and pastures, even if the differences among the different countries are very significant (**Figure 4**).

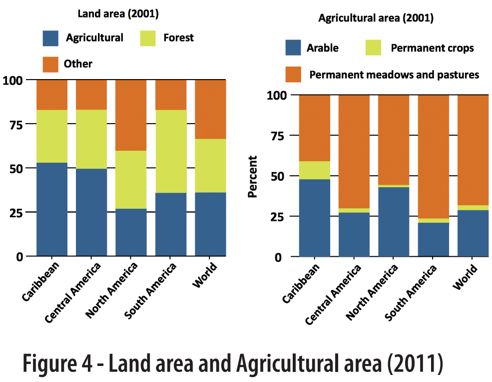

Figure 4 - Land area and Agricultural area (2011)
[Source: FAO, Statistics Division (FAOSTAT)]

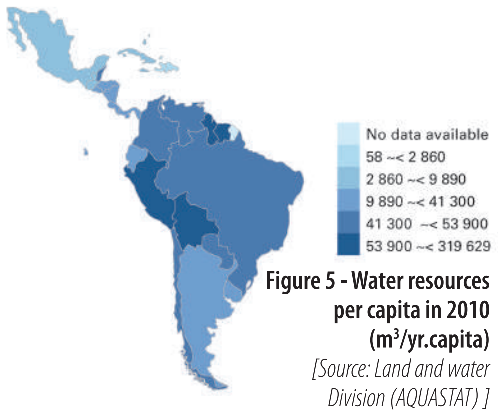

Figure 5 - Water resources per capita in 2010 (m^3/yr.capita)
[Source: Land and water Division (AQUASTAT)]

The per capita cultivated surface varies remarkably. In the small island states the population density is almost three times higher than in Central America and nearly eight times superior to that of South America. Argentina, with 0.96 ha/inhabitant, records the highest value.
According to AQUASTAT, the region, with 15% of world land surface, gets 30% of all rainfall and is characterized by 33% of the world's hydrological resources. It is estimated that the region's water resources are equal to 28,000 cubic meters per person per year, much higher than the world average (**Figure 5**).

The total figure of irrigated land is higher than 18.3 million ha and this represents 14% of arable land. The region's irrigation capability is estimated at 77.8 million ha. 66% of the theoretically irrigable surface is recorded in Argentina, Brazil, México and Peru.
It is possible to distinguish between irrigable land (equipped with irrigation infrastructure) and effectively irrigated land. In the case of Colombia only 36% of irrigable land is effectively irrigated. In other South American countries estimations are higher (92% in Argentina and 100% in Paraguay).

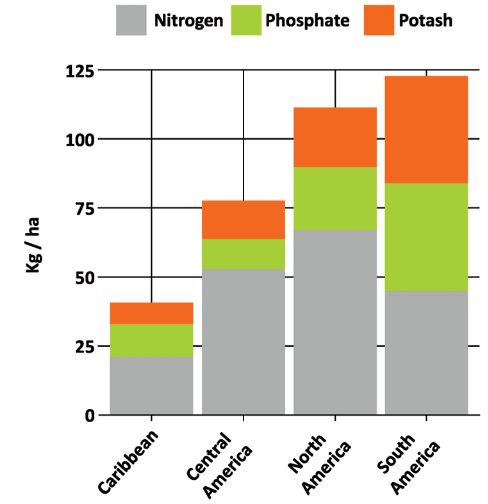

Figure 6 - Fertilizer consumption per ha of arable land and permanent crops (2011)
[Source: FAO, Statistics Division (FAOSTAT)]

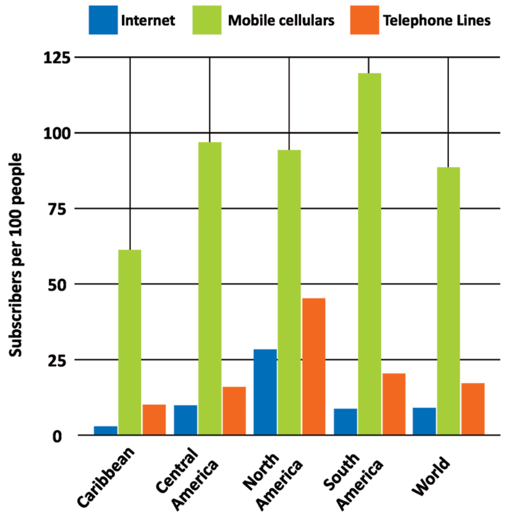

Figure 8 - Mobile cellular, broadband internet, and telephone lines subscribers (2012)
[Source: World Bank (WDI)]

INPUTS

The use of fertilizers increased in a sustainable manner between 2002 and 2012. In 2011, 45.7 kg of nitrogen per ha of agricultural land were applied, with a figure similar to the European one, and in any case smaller than that utilized in North America (67.3 kg/ha) and in Asia (61.2 kg/ha), although big differences are recorded in the region. In South America the quantities of phosphate and potassium fertilizers per hectare are three times higher than the ones distributed in Central America (**Figure 6**).

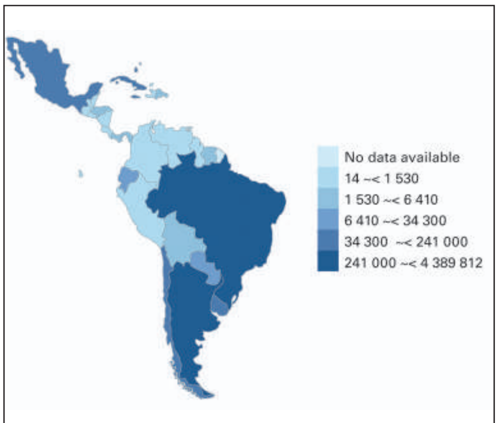

Figure 7 - Agricultural tractors, total (tractors, 2000-2010)
[Source: FAO, Statistics Division (FAOSTAT)]

The mechanization of agriculture in the region translates into an improvement in its efficiency. The biggest number of registered tractors is in Argentina, Brazil and Mexico, as these countries are to the ones with a higher agricultural surface and with a more developed agriculture (**Figure 7**).

The use of mobile phones and Internet transform into essential development means. In Latin America and the Caribbean the number of subscribers to fixed broadband and Internet is 7.7 per 100 inhabitants, slightly smaller than the world average (8.3) but much higher than the averages for Asia and Africa (**Figure 8**).

Table 1 - Summary of Latin American and Caribbean statistical data, relative to economic and social aspects
[Source: 6]

		Latin America geographical regions (*, only continent countries)				Some Southern countries		
	year	Mexico	North and Central America (*)	Caribbean	South America	Argentina	Brazil	Chile
Population and structure								
Total (M people)	2000	100.0	135.6	33.3	347.2	36.9	174.4	15.4
	2012	116.1	160.2	37.0	400.6	41.1	198.4	17.4
Rural (%)	2000	25.3	31.2	43.6	20.3	9.9	18.8	14.1
	2012	21.3	27.6	37.1	16.9	7.5	15.4	10.8
Agricultural (%)	2000	23.6	26.6	28.9	17.4	9.5	15.9	15.9
	2012	16.9	19.8	24.5	12.4	7.4	10.0	12.9
Economics								
GDP (kM $US)	2000	581	654	87	1338	284	645	79
	2012	1178	1363	119	4133	471	2253	268
Agricultural GDP (%)	2010/2012	4.1	4.5	4.6	7.2	10.1	5.2	3.7
Surfaces								
Total land (Mha)	2011	194.4	245.2	21.2	1728.8	273.7	845.9	74.4
Agricultural (%)	2011	53.1	49.7	53.9	34.7	53.9	32.5	21.2
Forestry (%)	2011	33.3	34.2	29.4	48.8	10.7	61.2	21.9
Agricultural (Mha)	2011	103.2	121.8	11.4	606.4	147.5	275	15.8
Arable (%)	2011	24.7	25.8	48.6	21.6	25.8	26.2	8.3
Permanent crops (%)	2011	2.6	4.2	11.3	2.3	0.7	2.6	2.9
Prairies and pastures (%)	2011	72.7	70	40.1	76.2	73.5	71.3	88.8
Agric. land per capita (ha/cap)	2011	0.25	0.23	0.19	0.36	0.96	0.40	0.10
Hydrological resources and irrigation								
per capita (m^3/(yr-cap))	1990	5423				24937	55015	69912
	2000	4574				22041	47201	59792
	2010	4031				20143	42232	53784
Potential irrigation (kha)	1987/2012	6300				1650	4500	1900
Effectively irrigated (%)	1987/2012	84				92	100	91
Labour								
Female employment (M people)	2010	17	23	6	75	7	40	3
Manly employment (M people)	2010	30	40	9	106	10	54	5
Agricultural employment (%)	2005/2012	13.1	15.1	16.2	14.7	1.3	12.2	10.6
Manly agr. employment (%)	2005/2012	80.5	81.2	73.2	80.2	74.9	81.0	74.3
Consumables								
Agricultural tractors (units)	2000/2012	238830				244320	788053	53915
Pesticides (kg/ha-agr.)	2008/2012	4.55				6.55		11.36
Nitrogen fert. (kg/ha-agr.)	2001	50.32	52.48	21.52	45.08	25.65	45.23	243.77
Phosphate fert. (kg/ha-agr.)	2001	8.58	11.03	10.14	39.08	18.47	51.22	68.77
Potassium fert. (kg/ha-agr.)	2001	12.28	14.16	8.38	38.46	0.82	59.55	39.93
Innovation								
Public investment in agriculture (% GDP)	2008	1.1				0.9	1.5	1.4

CHAPTER 5
AGRICULTURAL MECHANIZATION IN LATIN AMERICA

DEVELOPMENT AND ROLE OF MECHANIZATION

Agricultural environments in Latin America

The agricultural development of every region depends on its natural environment. Many failures of development politics are the consequence of the use in tropical and subtropical environments of techniques suitable for temperate agricultural zones. A high percentage of Latin American surface is considered as tropical and subtropical.

There are different classifications used to define agricultural environments. The Holdridge classification, utilized by FAO, adapts very well to the planning for land use and for rural development analysis in Latin America.

This classification is based on analysis of the environment using three variables: "bio-temperature" (0 - 30ºC), rain precipitation (P) and potential evapo-transpiration (ETP). Starting from these variables, with the ratio ETP/P it is possible to establish "humidity zones", which together with the bio-temperature (consequence of latitude and altitude) defines a combination of "life zones".

When the ratio ETP/P is greater than 1, the area is arid, while it is humid when the ratio is less than 1. This index is recommended by FAO as "the most reliable to foresee agricultural productivity and the population density in Latin America and the Caribbean since pre-Columbian times". If the Latin American capital towns are represented in a "life zones" diagram, 19 of them are stationed within border zones of the line ETP/P = 1. Exceptions are Lima and Santiago. The regions that are far away from this line, both of arid or humid type, are characterized by a low population density and by difficulties in agricultural development.

A more simple classification of agricultural environments, with respect to the one proposed by Holdridge, is based on four aspects: temperature, humidity, soils and slope. It is more operational, as the information necessary for its application is available in the FAO database.

In this classification, a basic point is the one relative to the growth period (GP), that is the period (number of days/year) in which the rainfall is greater than half the potential evapo-transpiration, plus the period necessary for the evapo-transpiration of 100 mm water, coming from rainfall and presumably stored in the soil.

Therefore it includes the humid periods (P>ETP) and excludes any period with temperatures less than 5 ºC. This classification establishes the following main climate zones (Agrological FAO Zones):

- Desert: GP = 0 days;
- Arid: GP = 1 to 74 days;
- Semiarid: GP = 57 to 119 days;
- Sub-humid dry: GP = 120 to 179 days;
- Sub-humid humid: GP = 180 to 269 days;
- Humid: GP = 270 to 364 days;
- Always humid: GP = 365 days.

If this climate classification is combined with the humidity and the temperature trend during the plant growing period, together with the main soil features, it is possible to differentiate the main agricultural environments, as can be seen in the following, for the different regions of Latin America [7].

Humid tropics

		Regions	Mha,	% surface
• Monthly averge temperature higher than 18 ºC. • Growing period: more than 9 months.	Great predominance of acid and not particularly fertile soils; high presence of insects and plant diseases; limited development of transport, storage and market infrastructure.	• Andean:	163	35.5
		• Brazil:	497	52.5
		• Caribbean:	52	71.7
		• Central Am.:	9	59.2
		• Mexico:	7	3.7
		• South cone:	0	0.0
		Total:	**748**	**34.4**

[Note: The total percentages include lands not suitable for agriculture. As a result the sum of the regional percentages is not always 100, because: non-agricultural lands are excluded; the lands considered do not exclude themselves reciprocally]

The humid tropics are the most extensive agricultural type in the region. They include half of Brazil and more than half of the Caribbean and Central America.
High temperature and rainfall make it possible to grow tropical species quickly. On the other hand a high soil percentage is characterized by limited fertility. When tree felling breaks the natural balance, soils remain without nutrients and their capacity to support crops is very limited. There are some soil areas that are more fertile, if associated with alluvial deposits or with richer organic matter, but the percentage of occupied surface is relatively small in comparison with the total. In addition, and generally speaking, these fertile zones do not occupy large compact areas, as they appear very fragmented within a large territory.
The growing period, longer than 9 months, makes it possible to have agriculture all year round. Anyway the lack of clearly defined periods for the plant growth cycle, from seeding up to harvest, imposes restrictions on the cultivation of some annual crops. In addition the consequences of plagues, diseases and weeds result more damaging because of the longer growing period, while the excessive humidity makes it difficult to perform agricultural tasks and crop harvesting.
However, there are areas with some drier months, which as a consequence are more suitable for annual crops, if the poor soil fertility does not prevent this practice. In the great majority of these situations, these zones are localized in the relatively high part of the Amazonian forest and in other humid tropical forests, where the soil fertility is not so low. Special reference must be made to the low areas (400 - 800 m above sea level) of the Andean mountains, where the young soils and a more favourable climate make it possible to cultivate pineapple, sugar cane, rice and corn. In the more humid zones the conditions are suitable for tree crops, such as oil palms, bananas, rubber and cocoa. Tropical woods offer excellent opportunities when they are combined with other production systems.

Semiarid tropics and subtropics

		Regions	Mha,	% surface
• Tropics and subtropics; one or more months with a temperature of less than 18 ºC and higher than 5 ºC. • Growing period: 3-6 months.	Short period suitable for crop growing, if surface is not irrigated; big risk of unexpected draughts; heavy consumption of irrigation water.	• Andean:	39	8.5
		• Brazil:	158	15.1
		• Caribbean:	11	15.7
		• Central Am.:	0	0.0
		• Mexico:	49	24.6
		• South cone:	44	10.0
		Total:	**301**	**13.9**

This environment includes 14% of the region's surface and has special importance in Mexico, where it covers one fourth of the country. It does not exist in Central America.

Soils are generally speaking less acid and sterile in comparison with humid tropics and, when there is water, may be very productive. On the other hand, and especially in South America, the problems associated with the presence of sodium and soluble salts are not rare. There are also acid soils and zones with scarce drainage and other edaphic limits; their importance is limited in comparison with the imposition of a long dry season. The variability of rainfall and the brevity of the growing period are often associated with harvest losses. The highest percentage of these areas is used as pastures for cattle, sheep and goats. In the irrigated areas it is possible to cultivate a large variety of very productive species.

Humid tropics and subtropics with acid soils

		Regions	Mha,	% surface
• Tropics and subtropics • Growing period: 6-9 months and acid soils	Soil scarce fertility; acid soils with a possible phosphor fixation; strong need of inputs for cultivation; limited withholding of nutrients in the soil	Andean:	49	10.6
		Brazil:	143	15.1
		Caribbean:	4	6.1
		Central Am.:	10	20.9
		Mexico:	4	7.1
		South cone:	14	3.1
		Total:	**235**	**10.8**

10% of Latin America and the Caribbean is included in this agricultural environment. Its importance is considerable in Brazil and the Caribbean, but very limited in the Southern Cone. It occupies large extensions in central Brazil, the eastern Columbian plains, the eastern and western Venezuelan plains and some zones in Bolivia and Paraguay.

The biggest part of the surface is covered with tropical savannah; dry season lasts 3-6 months. Limited work is necessary to clear off the land. This is mostly utilized for extensive cattle pasture; its grazing capacity is very low (about 0.2 head/ha). The predominant soils offer excellent physical conditions and are very suitable for mechanized agriculture; on the other hand, due to their high aluminium saturation and poten-

tial for phosphor fixation, they have a low capacity to supply and retain fertilizers and this feature limits their agricultural possibilities. The limited fertility of these soils is a consequence of the low phosphor content. When this deficiency is corrected and the acidity problem is solved, high outputs of corn, soya and sorghum may be obtained. Other agricultural solutions and livestock exploitation are also possible, if the fertility limits are exceeded.
In this environment there are some of the zones that offer most possibilities for an expansion of Southern American agriculture, but to obtain this result it is necessary to spread high quantities of phosphate, lime and other fertilizers.

Humid lands

		Regions	Mha,	% surface
• All climates • Soils swamped with water for more than 60 days	The bad drainage affects non-resistant crops; some areas may be flooded for a good part of the year.	• Andean:	60	13.1
		• Brazil:	99	10.4
		• Caribbean:	8	10.8
		• Central Am.:	8	17.1
		• Mexico:	12	5.9
		• South Cone:	64	14.3
		Total:	**251**	**11.5**

They occupy 11 % of the region. They are more common in Central America and in the Southern Cone, less in Mexico. In many places and in different topographical and edaphic conditions small, badly drained soil surfaces appear. In the Orinoco valley, Amazon basin, north of Bolivia and south-west of Brazil there are large areas with flooded soils or with the water table close to the surface.
The main limits are the unsatisfactory drainage and the flooding danger. Soils are made up with gley soils, and humid sub-groups of other soils. Organic soils are not common, apart from south of Chile and Guyana. Even if the soils present big differences as far as texture, acidity and fertility, generally speaking they have abundant nutrients. When they are properly drained and protected from flooding, they may be used with good results for the cultivation of paddy rice and other crops.

High slope lands

		Regions	Mha,	% surface
• All climates • Slope higher than 30 %	Limits for mechanized agriculture; transport problems; high soil erosion; additional problems with relation to rainfall, temperature and soil fertility	• Andean:	148	32.4
		• Brazil:	109	11.5
		• Caribbean:	9	12.3
		• Central Am.:	10	20.9
		• Mexico:	49	24.6
		• South cone:	68	15.3
		Total:	**399**	**18.4**

They have an extraordinary importance in the Andean zone, Central America and Mexico, reaching 20% of the region's surface. The land is cultivated through small subsistence farms, even if commercial exploitation of medium or large size is possible in favoured zones.
Slopes with a gradient of more than 30% make agriculture difficult and prevent its mechanization. Erosion affects its development and generally speaking agricultural production is scarce, as it is carried out without commercial inputs. In the drier zones the irregular rainfall causes frequent harvest losses and frost causes damage in the high altitude zones.
As a consequence of the altitude effect on the climate, it is possible to obtain many assorted crops, if water is available.

Lands without important limits

		Regions	Mha,	% surface
• Tropics, subtropics and temperate. • Growing period 9 months; no physical and soil fertility limit.	Without important limit due to climatic and edaphic factors. Even if unforeseeable draughts may harm rainfed agriculture.	• Andean:	13	2.9
		• Brazil:	22	2.4
		• Caribbean:	5	7.0
		• Central Am.:	5	11.2
		• Mexico:	3	1.4
		• South cone:	24	5.4
		Total:	**73**	**3.4**

The ratio of regional lands without any important limit for agriculture is considerably low, only 3%. The ratio is more favourable in Central America, the Caribbean and South Cone than in the other sub-regions. In absolute terms the largest zones with favourable climatological and edaphic conditions are found in Southern Cone (24 million ha) and in Brazil (22.5 million ha).
The biggest part of these lands has a temperate or subtropical climate, is covered by pastures with dark soils (rich in organic matter) and subsoils with high calcium carbonate. The majority of pastures may be used for different crops, forages and cultivated pasture exploitation. These soils are very suitable for intensive mechanized agriculture. Even if the majority of these lands is already cultivated, its production is much less than what could be reached by employing more fertilizers and improved varieties.

SOILS AND THEIR EDAPHIC LIMITS

The limits in relation to soil fertility and management are:

a) excess soil humidity (potentially suitable for paddy cultivation);
b) dry during more than 3 months (only one crop per year is possible);
c) low capacity to retain nutrients (lixiviation when fertilizers or calcium are applied);
d) high percentage of aluminium saturation, with compulsory high calcium application;

e) excessive aridity that could be detrimental for sensible crops like alfalfa or cotton; with a low percentage of aluminium saturation these soils may be very productive with suitable crops;
f) high capacity of phosphor fixation, with a consequent need for large amounts of phosphate fertilizers;
g) exploitation difficulty due to the presence of expansive clay, that makes cultivation difficult both in dry and humid conditions;
h) low potassium percentage, generally when soils have a limited capacity to withhold nutrients such as calcium and magnesium;
i) calcareous soils which may present some micronutrient deficiencies, even if they are generally speaking the most fertile (normally they need phosphoric fertilizers);
j) soils with excessive soluble salts, which need special directions for their washing, even if they permit tolerant crops when the salt level is acceptable;
k) soils with acid sulphate, generally saturated with water or inundated, that may produce sulfuric acid when drained; they allow inundated cultivation.

Availability of lands for specific crops

Plant growing depends on the temperature, but other climatic and edaphic factors also have an influence. Some factors are essential for growing, while others influence productivity. Some limits may be overcome by specific exploitation conditions, as estimations have to be calculated with three different input levels (FAO proposal).

At first it is necessary to calculate the maximum possible climatic efficiency for the considered conditions. After that it is necessary to consider the agro-climatic efficiency with different input levels, keeping in mind the soil specific conditions: texture, slope, etc.

Based on this, FAO establishes four categories of soil aptitude in relation to every crop and input level, comparing the agro-climatic efficiency and the possible maximum. These aptitude categories are:

Categories	Agro-climatic efficiency (possible maximum, %)
Very suitable	> 80
Suitable	40 - 80
Marginally suitable	20 - 40
Not suitable	< 20

In **Table 2** the soil surfaces that are suitable and very suitable for different food crops are pointed out, considering rainfed agriculture (not irrigated) with two exploitation levels: low, corresponding to subsistence agriculture, with abundant manpower and low or absent use of fertilizers and pesticides; high, corresponding to mechanized agriculture with a commercial direction, that needs high economic resources and sufficient distribution of fertilizers and pesticides.

Table 2 - Land surfaces suitable and very suitable for different food crops (total land percentage)
[Source: 7]

Crop	Andes		Brazil		Caribe		Central Am.		Mexico		South cone		Total	
	high	low	high	low	high	low	high	low	high	low	high	low	high	low
Cassava	12	12	25	25	29	21	19	18	4	4	3	2	16	15
Cotton	7	1	8	1	9	4	11	6	8	4	8	3	8	2
Corn	7	4	9	7	9	9	15	15	10	9	16	14	10	8
Beans	7	3	7	3	9	6	13	6	11	9	11	9	9	5
Paddy	15	7	11	4	18	12	25	11	6	3	5	4	11	5
Sorghum	5	2	3	2	9	7	10	9	9	8	7	6	5	4
Soya	8	2	9	4	9	6	12	6	8	6	7	5	8	4
Sweet potato	11	6	17	9	13	10	15	9	8	7	7	7	13	8
Wheat	1	1	1	0	0	0	2	3	5	5	11	8	4	3
Potato	1	1	1	0	0	0	4	4	4	4	9	8	3	2

AGRICULTURAL MECHANIZATION IN THE REGION

The information relative to the agricultural mechanization indices for some countries is scarce and not homogeneous, especially regarding the countries with a less mechanized agriculture. **Table 3** presents the summary of the data obtained from the FAO statistics.

Table 3 - Agricultural tractors available in some Latin American and Caribbean countries *[Source: 6, modified]*

	Tractors	Agricultural surface				
	Units	**Total** (kha)	**Arable** (%)	**Perman.** (%)	**Agr. ha /tractor**	**Arable ha /tractor**
Caribe						
Cuba	**72602**	6570	54.0	5.9	90.5	**48.9**
Dominican Republic	**1868**	2447	32.7	18.4	1310.0	**428.4**
North and Central America						
Honduras	**5200**	3220	31.7	13.7	619.2	**196.3**
Mexico	**238830**	103166	24.7	2.6	432.0	**106.7**
Panama	**8066**	2267	23.8	8.3	281.1	**66.9**
South America						
Argentina	**244320**	147548	25.8	7.0	603.9	**155.8**
Bolivia	**6000**	37055	10.4	0.6	6175.8	**642.3**
Brazil	**788053**	275030	26.2	2.6	349.0	**91.4**
Chile	**53912**	15789	8.3	2.9	292.9	**24.3**
Colombia		43786	4.8	4.3		**111**
Ecuador	**14652**	7346	15.7	18.8	501.4	**78.7**
Paraguay	**25823**	20990	18.6	0.4	812.8	**151.2**
Peru		21500	17.0	4.0		**250**
Uruguay	**36465**	14378	12.6	0.3	394.3	**49.7**
Venezuela		21250	12.2	3.1		**526**

It must be outlined that in the low developing countries there is agricultural exploitation with high technology agricultural machinery, used especially for industrial crop cultivation. Anyway in the majority of the farms mechanization is limited to the use of tractors for soil, tillage and seeding, in addition to the distribution of agrochemicals. Often some government organizations offer tractor mechanization services; farmers enjoy reduced hire rates and can also receive training.

Also, grain harvesting may be mechanized through the use of self-propelled combines. For some crops, such as sugarcane, manual cane cutting and the use of self-propelled machines may be carried out simultaneously. The socio-economic conditions and the abundance of manpower, together with the low countryside security due to frequent guerrilla presence, has limited the development of mechanization in some regions. Another factor in the limited mechanization is the lack of economically rentable technology, necessary to operate in tropical and subtropical climate conditions or on very sloping fields, which prevent the use of tractors.
Agricultural machinery manufacturing, except in Argentina, Brazil and Mexico, is carried out by craftsmen or by small industries with a local market; it is generally limited to hand tools and to simple soil tillage equipment. An exception is Chile, where the mechanization index is high; its technology is advanced and even precision agriculture is available, using imported equipment.

The case of Argentina

Agricultural sector

Agriculture and livestock have retained a basic role in Argentinian development during its history; in fact various agricultural and livestock activities had and still have an essential importance with regard to creation of the production value and for occupation of the countryside, the generation of employment and the economic rise.
At the moment the economic projection for the next decades, realized by specialized international organizations, foresees great dynamism for the world meat trade and for the inputs necessary to its production, such as grains and protein flours.
The employment generated by the agro-industrial chains in Argentina in 2003 was:

- *total employment:* 5,592,300 jobs, which means 35.6% of total employed people. This value includes the national government social plans aimed at promoting occupation (Plan Jefas y Jefes de Familia). If the people employed through this social plan are deducted, the total figure is reduced by 5% to about 30%;
- *direct employment:* 2,751,200 jobs, representing 49% of total agro-industrial employment.

Characterization of the different crops, as related to their technological level, is presented in **Tables 4 and 5**. In regard to extensive grain production, 82% of the surface is cultivated by producers, who apply a medium and high technological level; they produce 86% of the total. In the case of fruit crops only 8% of the producers apply a leading technology, producing 42% of the total. 14% of industrial crop producers utilize a high technological level, providing 50% of the production.

Table 4 - Output differences among different technological levels *[Source: 6]*

Crop group	Low-middle	Middle-high	Low-high
Grains	27%	24%	44%
Fruit crops	55%	38%	70%
Horticultural crops	18%	15%	44%
Industrial crops	37%	28%	55%

Table 5 - Surface, number of producers and production according to the technological level
[Source: 6]

Crop group	Technological level	Area (k ha)	Producers (thousands)	Production (k t)	Main crops
Cereals and oil crops	Low	3,187	38	7,015	Soybean
	Medium	8,413	75	24,564	Wheat
	High	5,103	28	19,545	Maize
	Total	**16,703**	**141**	**51,124**	Sunflower
Fruit crops	Low	64	14	532	Citrus
	Medium	80	8	1,864	Vineyard
	High	75	2	1,751	Apples
	Total	**219**	**24**	**4,147**	Pears
Industrial crops	Low	361	31	3,733	Cotton
	Medium	543	22	8,761	Sugar cane
	High	370	9	12,318	Tobacco
	Total	**1,274**	**62**	**24,812**	Mate
Horticultural crop	Low	27	4	516	Potatoes
	Medium	23	3	533	Garlic
	High	48	1	2,036	Onion
	Total	**98**	**8**	**3,085**	Tomato
Note: These figures are not the national total, as they come from different sources for which it was possible to obtain information.					

Industrial sector

Argentina had a large tradition for the design and manufacturing of agricultural machinery, as a consequence of a closed market [8]; later, due to total market opening, most of the traditional industrial units disappeared. Nevertheless, other manufacturers established their factories, to profit from the significant increase in direct seeding surface, mainly for soya beans and corn [11].

The main features of the Argentina agricultural machinery industry [4] are:

- large historic tradition, in parallel with the agricultural and livestock sector development;
- main section of Argentinean industry capital assets;
- high technological level of processes and products in the leader industries;
- business men highly engaged in the sector and highly qualified manpower;
- strong export growth in recent years, with diversification in the five continents;
- increased national production and import substitution in the last three years, mainly in the tractor and self-propelled combine sectors.

The main groups of Argentinean powered machines are harrows and cultivators, sowing machines, towed sprayers, combine headers, grain trailers, self-unloading hoppers, silos and grain driers, de-weeding machinery, balers, round balers and other forage equipment, milking and milk cooling machines. The main self-propelled equipment are grain, cotton and fruit harvesters, sprayers and fertilizer spreaders.

The main structural indexes are:

- market volume: About 1,400 million US$. It represents approximately 0.40 % of domestic GDP, while the sector production contributes 1.5 % to national industrial production;
- turnover of local industry: 5,800 M pesos (2013) and 6,600 M pesos (2014). Export: 179 M US$ (2013) and 118 M US$ (2014) (FOB).

- imports: 465 M US$ (2013) and 235 M US$ (2014) (CIF);
- manufacturers: About 850 enterprises. Sector heterogeneity with a strong presence of national small and medium companies;
- employment: 40,000 direct workers, with a high percentage of qualified manpower, and about 50,000 indirect workers. As an average every company has 60 workers.

The strong points of Argentinean industry are:

Seeders. Market: about 3700 units in 2011; 2300 units in 2012 and 2013; 1500 in 2014. Turnover about 1000 M pesos in 2012 and 1200 M pesos in 2013 and 2014. Low import percentage (<5%). Exports decreased in 2003-14; after reaching about 46 M US$ in 2012, in 2013 and 2014 they settled to about 23 M US$; Their share in agricultural machinery exports is around 15%. Seven companies hold around 70% of the market; the other 50 manufacture the remaining 30%. The Argentinean industry is highly innovative in the direct seeding process. The present fleet is estimated to number 50,000 usable seeders, with an average useful life of 12 years; annual replacement is considered to equal 4,500 units/year, accompanied by an obvious process of fleet modernization.

Self-propelled combines. Market: 1140 units in 2010-11; 686 units in 2012; 908 units in 2013 and 566 units in 2014. Turnover about 2200 M pesos in 2014; import about 70-75 % in recent years, coming from Brazil, USA and Europe (John Deere, AGCO, Case/New Holland from Brazil and Claas from Europe). In recent times national production participation is increasing. Important growth of exports, even though there was a decline in 2014; in 2011 and 2013 exports reached about 40 M US$ and in 2014 dropped to about 20 M US$; a relevant participation in exports was the Venezuela market. A single manufacturer concentrates the highest part of the national production (Vassalli Fabril). The process of import substitution by the biggest manufacturers (John Deere, Case, NH, Claas and AGCO) must be underlined. The present fleet is estimated at 20,000 usable combines, with an average useful life of 15 years and an average age of 11.5 years.

Tractors. Market: about 5000 units in 2011-12 and 2014; 7500 units in 2013. Turnover about 1,800 and 3,600 M pesos in 2012 and 2013 and 3,200 M pesos in 2014. Import participation close to 60 %, with new national manufacturing projects and increase of domestic production in 2013. Market is dominated by big global enterprises: John Deere, AGCO, Case New Holland (CNH), Valmet (Brazil). Almost the total national production is sold in the country. Moderate increase in exports during the period 2003-14; in 2012 exports reached 40 M US$, down to 20 M in 2013 and to 10 M in 2014. Main manufacturers: Pauny, Agrinar, Metalfor. Prominent process of industrial revival from 2002, starting from pre-existing capacities. The present fleet is estimated at 60,000 tractors. From 2003 the fleet has been updated, even if there is a high degree of obsolescence.

Self-propelled sprayers. Market: about 900 units in 2012 and 2013; 600 units in 2014; import participation 20%, coming from Brazil and USA. Exports with a moderate rise in 2003-14 (2012, 16 M US$; 2013, 12 M; 2014, 10 M); there are about 10 manufacturers, but 2 companies hold around the 70% of the market; these two enterprises are also manufacturing in Brazil (Metalfor and Pla).

Starting from 2002, the Argentinean industry showed a strong recovery (after a very long crisis), both in

turnover and in units sold. This recovery included all the industrial sectors and went on continuously until a peak in the demand was reached in 2007. The agricultural machinery industry took part in the significant increase and modernization of the agricultural and livestock sectors, based on the introduction of genetically modified crops and of new seeding methods, which caused a growth in productivity; this fact was accompanied by an important increase in the world market price of grains. As a result there has been a permanent process of technological inclusion in the manufacturing industry (strong implementation of precision agriculture for grain production).
With the renewed economic growth in Argentina and, in a parallel manner, with the structural changes in the production means of agricultural and livestock sectors, the agricultural machinery industry turned itself into one of the most dynamic sectors of Argentinean industry, providing dynamism to the agricultural and livestock dynamism with a wide range of capital assets.

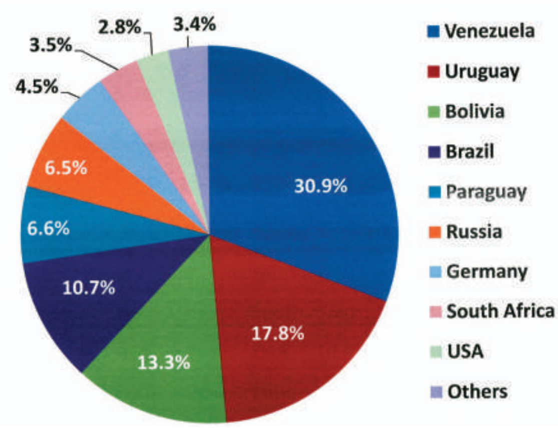

Figure 9 - Total Export of Argentinean industry
[Source: 4]

The new sowing methods made possible modernization and strong technological inputs into the sector. These factors, at the same time, contributed to the progressive recognition of the industry in the international market, due to its quality and technology.
In a parallel manner to the growth of production and of the internal market, exports strongly increased in the last decade, with a high insertion in Latin America. Exports to other markets enabled the Argentinean agricultural machinery industry to sell, at present, in all five continents (**Figure 9**).

The case of Brazil

<u>Agricultural sector</u>

In its 8.5 million square kilometers, Brazil offers different landscapes, ranging from semi-desert to evergreen tropical rainforests [1]. It is regarded as one of the richest countries in biodiversity. The Amazon, an area of nearly 5 million square kilometers, occupies the northern part of South America up to the Andes. The Amazon forest is a tropical rainforest with one of the world's highest rates of biodiversity, having nearly 80% of its total area preserved. A summary of the main agricultural features of Brazil is presented in **Table 6**.
The different crop surfaces and the grain production are presented in **Tables 6 and 7** (2007/2008). The increase of cultivated areas has been possible as a consequence of the introduction of conservation agriculture with surface residues (direct sowing). This practice is now applied to tropical and subtropical regions following the experimentation carried out by EMBRAPA and other public and private organizations.

Table 6 - Cultivation surfaces in Brazil (M ha in 2007) *[Source: 1]*

Brazil (total land)	**850**		
Total Preserved areas and other uses*	510 (60%)		
Total arable land:	340 (40%)	% total land	% arable land
1 Cultivated Land: All Crop	63.1	7.4%	18.6%
Soybeans	20.6	2.4%	6.1%
Corn	14.0	1.6%	4.1%
Sugarcane**	7.8	0.9%	2.3%
Sugarcane for ethanol***	3.4	0.4%	1.0%
Oranges	0.9	0.1%	0.3%
2 Pastures	200	23.5%	58.8%
3 Available land (ag, livestock)	77	9.1&	22.6%

Notes:
* *These areas include Amazon Rain Forest, protected areas, conservation areas and cultivated area for sugar an ethanol production*
** *Cultivated area for sugar and ethanol production*
*** *Harvested area for ethanol production*

Table 7 - Grain production in Brazil (season 2008) *[Source: 1]*

Product	**Grains Production (m ton)**	**Planted area (m ha)**	**Grains Productivity (kg/ha)**
Cotton	2437	1095	2225
Rice	11955	2928	4083
Bean (total)	3437	3831	897
Corn (total)	56233	14470	3886
Soybean	59989	21158	2835
Wheat	3824	1819	2102
Other	2899	1400	
Brazil	**140774**	**46701**	**16028**

In addition it must be underlined that Brazil is the first world producer of coffee (2.4 Mha and 32 M bags of 60 kg) and of citrus fruits (1.15 Mha and 93.8 Mton) and the third of bananas (506.9 Mha and 6.9 Mton). In Brazil there are around 4.5 million farms; of them, half a million is highly mechanized and devoted to commercial crop production. The other 4 million generally have a surface between 20 and 40 ha; normally the majority is not mechanized, even if many of them are economically viable, due to the type of crop cultivated. These small and medium farms occupy a high percentage of the rural population and are the basis of the country's food production.

Industrial sector

Brazil has a long tradition in tractor and agricultural machinery manufacturing [13]. The tractor industry began in 1920, when Ford was authorized to operate in that market. In a small time Ford started to assemble the Fordson tractor, imported from USA. In the middle of the Twentieth century other tractor, implement and agricultural machinery industries settled in Brazil (Allis-Chalmers, Massey Ferguson, John Deere, Caterpillar and Fiat). Starting from 1960 Brazil initiated its own production.

In 1964 the Brazilian enterprise Agrale put on the market its compact tractor, the 4100 type, still now on sale. In 1965 John Deere began its production, in the beginning with self-propelled combines (Schneider & Logemann e CIA Ltda. -SLC-); it settled in Horizontina (Rio Grande do Sul), where to-day it is manufacturing combines and other agricultural machines.

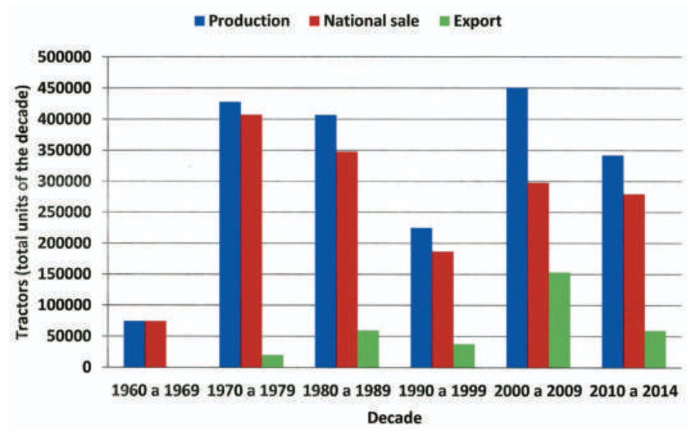

Figure 10 - Manufacture and sale of tractors in Brazil *[Source: ANFAVEA]*

The Brazilian tractor industry recorded a low rise up to 1970, but in the following years underwent an important growth up to 1976, when it reached the goal of 64.2 thousand tractors produced, and this record was only broken 32 years later, in 2008, when total production was 66,500 units (**Figure 10**).

The initial market rise was a consequence of the beginning of soya bean cultivation in Brazil, and the second one was mainly due to the establishment and implementation of two agricultural credit plans and to the tractor and machinery export rise, which began from 2000. Starting from that year two government plans were established: MODERFROTA (Modernization of the fleet of agricultural tractors, implements and combines) in the year 2000; Mais Alimentos (More Food) in 2008. Their main objective was to increase agricultural productivity, through access to credit for agricultural machinery purchase. Due to the very favourable moment in Brazilian agriculture between 2010 and 2013 the highest level of tractor manufacturing was established.

In the decades between 1980 and 2000, the national situation went through big difficulties with regard to agricultural tractor production, due to the instability created by different economical crises, both at national and world level, by modifications in the monetary exchange and by fewer purchase incentives. At the moment there is a reduction in production as a consequence of the country's economic crisis.

The most common tractor power ranges in Brazil are comprised from 50 up to 99 HP (38-76 kW) and from 100 up to 199 HP (76-152 kW), highlighting the first of these. This is a consequence of the large number of small acreage farms (less than 20 ha) and to the government subsidy, through low interest credits for small farmers.

The Brazilian market of high power tractors is small and it relates to sugar cane cultivation, to the big land extensions of the "Centro-Oeste" ("Centre-West with the provinces of "Mato Grosso", "Mato Grosso do Sul" and "Goiás") and to the new areas of agricultural frontier expansion. This part of the market is dominated by John Deere and New Holland. The majority of the tractor manufacturers are established in the south of Brazil, exactly in the provinces of "Rio Grande do Sul", "Santa Catarina" and "Paraná".

At present the Brazilian market of agricultural tractors is very active and offers a wide variety of tractors for small, medium and large farmers. There are 16 manufacturers, which produce 239 tractor models with the widely differing configurations and power ranges. The tractor and grain combine market statistics are published by ANFAVEA [3], which considers only the associated makes (Agrale, Case IH, John Deere, Massey Ferguson, New Holland, Valtra). The last year's tractor and grain combine manufacture and market are resumed in **Table 8**.

Massey Ferguson (AGCO) is the leader of Brazilian tractor sales, with an average share of 25.65% in the last four years. In 2013 Valtra, another enterprise of AGCO Group, took over the second position. In 2013 the sales of the first four manufacturers (Massey Ferguson, John Deere, New Holland and Valtra) resulted very balanced, with a difference of only 4.9% between the first (Massey Ferguson) and the fourth (New Holland). Following ANFAVEA in the last year Massey Ferguson and John Deere consolidated their position, while Valtra lost its position. From 2014 there has been a strong fall in sales by all the manufacturers, as a consequence of the local economic crisis.

In addition to tractors, in Brazil there is construction of self-propelled grain, and sugar-cane, cotton, coffee and peanut harvesters. In the last three years a high fall in the market has been recorded, as it is possible to observe in **Table 8**.

Table 8 - Brazilian tractor and self-propelled combine market (only ANFAVEA members)
[Source: 3]

Years	Tractors			Combines (grain)		
	Production (units)	National sales (units)	Export (units)	Production (units)	National sales (units)	Export (units)
AGCO (Massey Ferguson)						
2013	22026	15878	5916	1133	893	148
2014	18578	13563	5497	947	651	283
2015	14065	9160	4098	464	404	119
Agrale						
2013	2345	2087	84			
2014	2451	2022	454			
2015	1528	1340	162			
CNH (Case)						
2013	4939	4500	286	1726	1562	157
2014	4264	3894	179	1217	1086	57
2015	2281	2299	160	550	607	31
CNH (New Holland)						
2013	14712	12705	1331	3263	2656	283
2014	12296	10031	1351	2347	1822	309
2015	7322	6897	1147	1102	1215	115
John Deere						
2013	14618	13453	1546	3432	3124	526
2014	12865	12426	865	2944	2667	3708
2015	8065	8041	468	1658	1567	105
Valtra Brazil						
2013	16435	14070	1925	379	302	11
2014	12184	11151	1070	155	222	2
2015	9403	7976	1208	115	124	13

The manufacturing of PTO driven machinery has a long tradition. In the decade of 1940 Jumil was the first enterprise to produce a sowing-fertilizing machine with a pneumatic system for distributing seeds, thus offering precision sowing. Jacto keeps the priority of manufacturing the first atomisers. Marchesan (Tatu), in 1946, began the manufacturing of implements to be drawn by the tractors.
In 1979 the Brazilian Association for Machines and Equipment Industry (Associação Brasileira da Indústria de Máquinas y Equipamentos, ABIMAQ) [2] was founded. One of its sections, named CSMIA, includes some 180 companies, that manufacture all types of agricultural machinery and equipment.
The trade figures for the agricultural machinery sector in Brazil (in 2007) were as follows:

	M US$ FOB
1. Sales Turnover:	3,023 ,40
2. Foreign Trade	
2.1- Exports:	685,857
2.2 - Imports:	193,129
3. Number of Employees	**40,957**

The position of ABIMAQ with respect to the Brazilian situation may be summarized:

- agriculture should be seen not only as a source of food and raw materials for industry, but also as a source of clean energy;
- sustainable agriculture, food safety and environmental protection are a must;
- demand for a better quality food will grow consistently;
- in the development of new machinery it is essential to consider 3 key elements: the operator, the land and the environment, all combined in harmony;
- both the design and performance of agricultural machinery should be adapted to the different kinds of soils, topography (terrains), climates and operators; safety regulations and certification are also very important;
- technological progress should be continuous, considering also social, cultural, economic and human factors;
- problems are becoming more and more universal and should be treated jointly;
- cooperation between nations, companies and people is the priority, therefore at ABIMAQ a joint-venture program has been developed.

The case of Mexico

Agricultural sector

With an arable surface of 24.8 Mha, 2.5 Mha of fruit cultivation and 80 Mha of pasture, Mexico produced (2004):

	kton		k
Cereals	32751	Oilseeds (oil equiv.)	447
Meat	5040	Sugar crop	45127
Fruits & Vegetables	24772	Stimulants	359
Roots $ Tubers	1890	Tobacco	22
Pulses	1752	Fibre Crops	147

34% of its population is working in agriculture. Farms are usually very small; 85% of farmers do not own more than 5 ha of cultivable soil, and among them 90% does not reach 3 ha. As a consequence small and light machinery is needed [5].

Industrial sector

The available tractors are too expensive for individual farmers in the Mexican agriculture subsistence sector. It is necessary to have the availability of tractors, which are appropriate not only to the farm's small area but also to the low technological level prevailing in the sector (skill in repairing, operation and spare parts supply).

As a consequence of the importance reached by agricultural tractors imports until 1965, the Federal Government developed a policy aimed at producing these machines locally. The four makes, that presented a manufacturing plan and that could satisfy the fixed requirements, were in 1966 International Harvester and John Deere, and in 1967 Massey Ferguson and Siderúrgica Nacional S.A. (Gallardo, 1977).

At present ,four enterprises manufacture tractors in the country. Factories are as follows:

- John Deere has three plants, one in Garza García, Nuevo León, for agricultural implement fabrication (subsoilers, ploughs, harrows, sowers, forage shredders, cultivators and soil shredders). The others are in Santa Catarina, Nuevo León, for the manufacture of front-loaders and components for industrial equipment, and Planta Saltillo, Coahuila for tractor manufacturing;
- the Mexican CNH is an enterprise charged with the production and selling of Case and New Holland tractors and agricultural machinery, with plants in Queretaro, Qro. and Silao, Gto. CNH Global N.V. was in 2004 the successor of New Holland N.V, and its final name is now CNH de México S.A.;
- AGCO of Mexico began its operations in 1967 with the mark Massey Ferguson, and later on it incorporated products with the mark Challenger. In 1996 AGCO Corp. acquired the facilities located in Queretaro to manufacture agricultural tractors in the country;
- McCORMICK Tractores de México is a tractor enterprise that began its activity in 2003; it is localized in Silao, Gto. In this plant McCormick tractors are assembled (8 different models from 40 HP (29.8 kW) up to 230 HP (171.5 kW).

According to the CIIDRI (Centro de Investigaciones Interdisciplinarias para el Desarrollo Rural Integral) the Mexican market (2008 investigation) is very stable, with average yearly tractor sales of 10000-11000 units; since 1997 the tractor cost oscillates between 16,000 and 60,000 US$.

In 2004 the potential market was estimated at between 15,000 and 18,000 units, but sales were only 11,000, and this represented a clear deficit with respect to the total production; at present the companies dedicated to tractor manufacturing are producing around 85-90% below their capacity.
Considering an agricultural frontier with 24 Mha, with a mechanizable surface of 18.6 Mha, about 360,000 tractors would be necessary, with powers of 50-60 HP (37.2-44.7 kW). The present fleet is estimated at 217,300 active tractors, representing 60% of the mechanization necessity.

CONTRIBUTION OF THE CLUB OF BOLOGNA

The contributions relative to Latin America, as along with other reports made by regional speakers regarding global interest themes viewed from a local perspective, were discussed in:

- year 1991 - Bologna (Italy). III Members' Meeting. Bologna (Italy) - EIMA International. Country Reports: A preliminary overview;
- year 1995 - Bologna (Italy). VI Members' Meeting. Bologna (Italy) - EIMA International. Session 2 - Technological levels needed in the various agricultural areas;
- year 1996 - Bologna (Italy). VII Members' Meeting. Bologna (Italy) - EIMA International. Session 1 - Cooperation between Research Institutions and Industry;
- year 1997 - Bologna (Italy). VIII Members' Meeting. Bologna (Italy) - EIMA International. Session 1 - Contractors;
- year 2000 - Fortaleza (Brazil). 1st Latin-American Meeting of the Club of Bologna (4 July);
- year 2006 - Bologna (Italy). XVII Members' Meeting (Second Session). Bologna (Italy) - EIMA International.- Influence of legislation/subsidies, to help agriculture and/or agricultural mechanisation, on the market of agricultural machinery;
- year 2009 - Hannover (Germany), Agritechnica, 08 November; XX Members' Meeting.- Session 2 - Innovations for Sustainable Agricultural Mechanisation;
- year 2011 - Hannover (Germany), Agritechnica, 13-14 November. XXII Members' Meeting "ENERGY USE OF BIOMASS: A CHALLENGE FOR MACHINERY MANUFACTURERS". Session 1 - Agriculture and energy;
- year 2013 - Hannover (Germany), Agritechnica, 10-11 November. XXIV Member's Meeting "INTERNATIONAL STANDARDS: OPPORTUNITY OR PROBLEM". Session 2 - Standard users.

DEVELOPMENT OF CURRENT RESEARCH AND FUTURE PROSPECTS

Agriculture and its mechanization in Latin America present significant differences between the regions, due to the agro-climatic and socioeconomic variability. There are regions, especially in the south cone countries, where conservation agriculture is carried out with advanced mechanical technology. It includes Precision Agriculture systems and has turned into one of the essential factors in the world grain trade.

On the contrary, in large areas of Central America, the Caribbean and Andean Countries subsistence agriculture is practised; it is a "lifestyle" for a high percentage of the population. The experience developed by EMBRAPA in Brazil may help modernization of small agricultural exploitations in tropical and subtropical areas and also may be useful to realize a sustainable professional agriculture in some areas of countries like Paraguay and Bolivia.

Mechanization of small farms [12], just as for the big ones, results very difficult and sometime impossible in specific conditions of the physical environment. The high slopes, the stones or the low soil supporting capacity, due to the important water content (inundation) are factors that make practically impossible the use of machinery or that require the utilization of very specialized tractors and implements. This special machinery is difficult to make profitable, due to the high erosion problems which may be met in the Andean regions or in the tropics, when the soil is not protected by plant cover, even if the direct seeding technique appears to be an interesting alternative to extend the agricultural frontier in tropical areas, where associated crops are a must.

In these situations the only motorized machines that may work, are walking tractors or motor-mowers, even if with a clear disadvantage in comparison with draft animals in the highest proportion of agro-economic conditions. The solutions used in certain agricultural zones in Europe or in Japan are unfeasible from an economic perspective, unless there is strong and continuous state assistance.

It is always necessary to consider the consequences of mechanization on the family income, as a percentage of the money will be used to compensate for purchase of machinery, fuel and other goods necessary to operate agricultural equipment. The professional training regarding mechanization assists in reducing working costs and makes it possible to directly repair and maintain machinery. Professional training may also improve the local repair shops, which may transform themselves into small mechanical equipment manufacturers, necessary for the tractors in the different field operations.

On the other hand, the promotion of contractor enterprises with the participation of local farmers, who may carry out this activity as a complement to their agricultural activities, opens better perspectives for a full development of any agricultural activity and of the local repair and technical assistance shops. Finally, this upgrading prevents the machinery bought with subsidies from being transformed into scrap as soon as it is available for agricultural operations.

It is also important to direct small farm production to crops that necessitate more manpower, as their full mechanization results more difficult. In fact, small farmers have the advantage of the availability of family manpower, which may be utilized part-time or at high intensity when needed during the critical periods.

On the big exploitations devoted to grain and other industrial crops, the implementation of Precision Agriculture starting from harvest maps permits application of inputs with a variable dosage. This makes it possible to reduce production costs and environmental impact, especially on poorly homogeneous soils and those with phosphor and potassium deficits.

On the other hand, the widespread availability of water in some region recommends an increase in irrigated surfaces, that may compensate for the scarcity in rainfall during critical years and so stabilize production.

An important factor is the shortage in rural areas of infrastructures necessary for harvest displacement and for grain storage and conservation. These points contribute to increase the costs of agricultural product marketing and of harvesting and storage losses.

A balanced development

Development of the rural zones must be performed together with that of the equipment, especially considering the situation of the countries and economic areas where they are placed. It is not possible to obtain adequate agricultural development independent from the industrial one [9] [10].

If the *International Organizations* are considered, it is necessary to remember that, in accordance with the governments, they order, programme and decide the assistance projects, even if they do not always consider some priority parameters, such as:

- the project duration must be suitable to the development need; therefore very long. This principle diverges with the national and international demagogy. According to the different cases, it is necessary to select the right duration and it is necessary that the two sides clearly know the result of their decisions;
- for each project, the absolute priority must be training. It is necessary to properly select experts and local staff that know how to train and be trained. In the short term, the projects are usually designed with many plants/equipment/tool-machines/instruments, probably bound not to be used or to become obsolete. In the long term the situation is the opposite, with real possibilities for agricultural and/or industrial development.

The *Governments* constitute the balance point for industrial development. They must be convinced that too high import duties and/or import bans are harmful for the national industry and the country. A moderate protection may sometime be necessary, but always limited. The appropriate measures could be:

- inflation reduction and control;
- continuous development policy, without abrupt changes of objectives and methods; international agreements (common markets, etc.) for industrialization, commercialization, etc.;
- adequate import duties policy that will not produce monopoly situations, competence cancellation and qualitative product decline;
- limited, rational and efficient bureaucracy;
- standardization of raw materials, products and requirements.

Regarding the *Enterprises* it must be stressed that the technological collaboration company-company, among entities of two countries, one developed and one developing, is difficult. From the two sides, the entrepreneurs want to sell, and to earn. Collaboration is only possible when a common and mutual interest exists.

The huge advantage of the developing countries industry is the limited cost of manpower (4 or 5, up to 10 times less), with raw-materials and final product prices comparable with those of the developed world. To collaborate with success with the developed world, the Latin American industry has to take the following measures:

- increase product quality; secure delivery terms; facilitate relations among different enterprises;
- promote and follow standards. Often technical offices and entrepreneurs are not even aware of the standard's existence. On the contrary, designers from developed countries are compelled to spend more time following standards (national, ISO, OECD, EU directives, CEN) than carrying out the usual design and development activities;
- utilize high quality raw-materials and components. Often the lack of this principle avoids agreements, collaborations and exports;
- finally, limit its profit in a reasonable manner. An European or American entrepreneur is accustomed to profits that with difficulty are bigger than 20%; he does not understand the requirements of his developing country colleague, that consider meagre a 100% profit (thanks to inflation, to government instability, to the unknowns of industrial and import/export tariff policy). As a result, this factor and the above mentioned technical parameters frequently cancel the advantage of low manpower costs.

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CHAPTER 6

AGRICULTURAL MECHANIZATION IN CHINA

CHAPTER 6
AGRICULTURAL MECHANIZATION IN CHINA

BY **MINLI YANG** (CHINA); **BING ZHAO** (UN WORLD FOOD PROGRAMME)

INTRODUCTION

Theodore W. Schultz, an American agricultural economist, thought that agriculture would become the economic growth power if the traditional agriculture could be transformed into modern agriculture in developing countries. China is a big agricultural country with a large population. The development of modern agriculture is a significant contributor to the wellbeing of the Chinese people. Agricultural machinery and equipment provide the base of material technology for modern agriculture, and agricultural mechanization is a major content and one of the main indicators of agricultural modernization. The Chinese government always attaches great importance to agricultural mechanization development, and agricultural mechanization becomes important support to promote the transformation of agricultural development methods, to improve agricultural labour productivity and agricultural comprehensive production capacity in China.

AGRICULTURE SITUATION

In 2014, China's agricultural population was 619 million people, about 45.2% of the total population. The percentages of employees in primary, secondary and tertiary industry were 30%, 30% and 40% respectively, and the composition of gross domestic product of primary, secondary and tertiary industry was 9%, 43% and 48% respectively. China's per capita agricultural labour productivity is RMB25, 600 (US$3,900) (**Table 1**), while the annual net income per farmer was RMB9, 900 (US$1,500), with an income gap between urban and rural areas of 2.97:1.

China has a total arable area of 120 million ha with hilly mountainous areas of more than 60%. Total sown areas of farm crops is 166 million ha, of which 113 million ha are for grain crops, i.e. 57% of the total sown area. In turn, the total sown area of corn, rice and wheat is 78% of the sown area of grain crops, and sown areas of corn, rice and wheat are 39%, 30% and 25% of total sown area of corn, rice and wheat respectively (**Figure 1**).

Year	Gross labor productivity (Yuan)	Agricultural labor productivity (Yuan)
2000	7900	4100
2001	8600	4300
2002	9400	4500
2003	10500	4800
2004	12300	6100
2005	14200	6700
2006	16500	7500
2007	20200	9300
2008	23700	11300
2009	25600	12200
2010	3000	14500
2011	35200	17900
2012	38400	20300
2013	43200	23600
2014	46500	25600

Table 1 - China gross labour productivity and agricultural labour productivity from 2000 to 2014
[Source: China Statistics Yearbook]

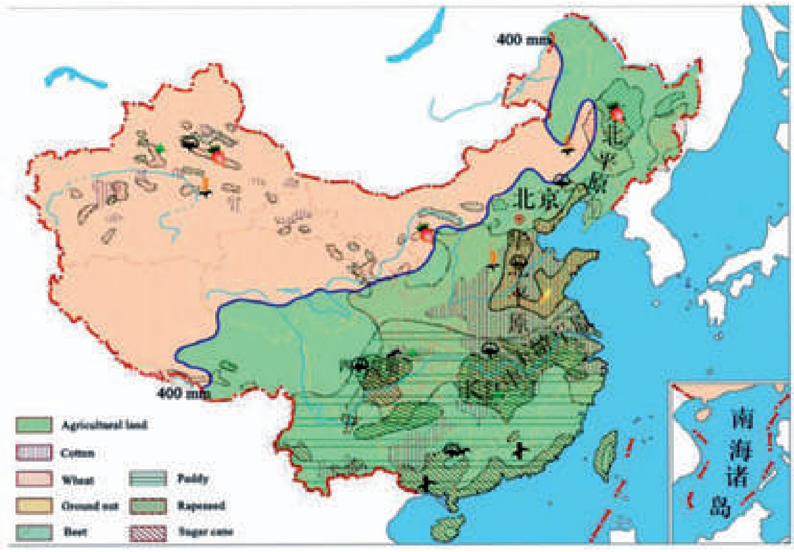

Figure 1 - Major Agricultural Land and Main Crop Regions of China

China's per capita arable land and fresh water resources are rather low, at the levels of only 25% and 40% of the world's average. China's per capita arable land availability is 0.08 ha, far below the world average of 0.24 ha. But China's total output of grain, vegetables, fruits, meat and aquatic products respectively ranks first in the world. In particular, China's grain output increased for twelve consecutive years from 2004 to 2015 (**Figure 2**), and it reached 621.44 million tons in 2015. It would not have been possible to achieve these gains without fast agricultural mechanization development.

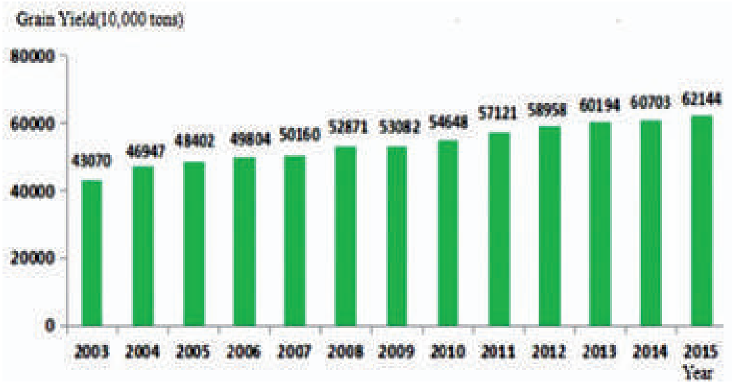

Figure 2 - Grain Yield in China from 2003 to 2015

THE SITUATION OF AGRICULTURAL MECHANIZATION

Since 1949, China has seen a remarkable development in agricultural mechanization, which has been playing a very important role in promoting the progress of modern agriculture, ensuring agro-product supply, guaranteeing food safety, increasing competitive ability of agro-product and raising farmers' income, and also supporting the rapid growth of national economy. It will be presented in five aspects as follows.

The ownership of agricultural machinery has increased rapidly

By the end of 2014, the original value of farm machinery reached RMB 878.8 billion, averaging RMB 3,400 per peasant household, making up 65.4% of the fixed assets of agricultural production for them. The total power of farm machinery had reached 1,080 million kW, which increased by 9.2 times compared with that of 1978 of 118 million kW. The average power availability per hectare now stands at 5.4 kW. Some agricultural machinery including large-mid-sized farm tractors and implements, combine harvesters and farm load-carrying vehicles, increased quickly and reached 5.68 million, 8.89 million, 1.58 million and 13.77 million units respectively. The matching implement ratios for large-mid-size farm tractors and small-size farm tractors are 1:1.56 and 1:1.77, respectively.

The mechanized operation level is rising steadily and the service field of agricultural machinery is spreading gradually

By the end of 2014, China's crop production comprehensive mechanization level reached 61.6% (**Figure 3**). The mechanization percentages of plowing, sowing and harvesting reached 77.5%, 50.8% and 51.3% respectively (**Table 2**). In the case of wheat, 87.0% of sowing and 93.3% of harvesting had been mechanized. For paddy rice, mechanization rates of planting and harvesting reached 39.6% and 83.1%, and mechanization percentage of corn sowing and harvesting reached 83.9% and 56.7%. Mechanization levels for paddy rice and corn are comparatively lower, especially for rice planting and corn harvesting. The mechanization level of potato sowing and harvesting, rape sowing and harvesting, peanut sowing and harvesting, cotton harvesting and sugarcane harvesting are also relatively low (**Table 2**). There are 20 provinces, municipalities or autonomous regions with integrated mechanized levels of over 50%, and 11 of them are over 70%. The total area of greenhouses is 20.8 billion m^2 all over China. At present, the field of agricultural mech-

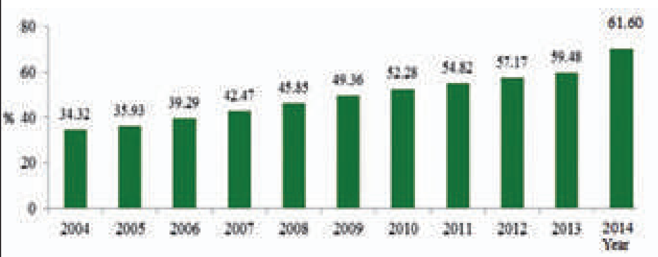

Figure 3 - China's crop production comprehensive mechanization level from 2004 to 2014

	Tillage Mechanization level	Planting Mechanization level	Harvesting Mechanization level	The comprehensive level of tilling, planting and harvesting
Crop	77.5	50.8	51.3	61.6
Wheat	100	87.0	93.3	94.1
Rice	98.1	39.6	83.1	76.0
Corn	97.4	83.9	56.7	81.1
Potato	55.9	24.3	23.0	36.5
Cotton	100	86.5	15.2	70.7
Rape	68.0	19.5	24.9	40.5
Peanut	65.9	40.7	29.4	47.4

Table 2 - Crop production mechanization level in 2014 (%)

anization has expanded from grain crops to cash crops, from field agriculture to facility agriculture, from crop farming to breeding industry and agro-product processing, from field production to before-production and post-harvest.

Remarkable science and technology innovations in agricultural mechanization

In recent years, there has been a marked progress in technological innovation, which provides a great technical support to increase mechanization levels. For example, in view of key links for main crops' production, the technology and equipment for mechanized paddy production such as transplanting and harvesting and the harvesting machinery for corn has become more mature and brought into big area extension. In addition, there has been a large progress in the fields of conservation tillage, straw crushing and re-utilization, pasture production and processing, sufficient and safe chemical application, planting and harvesting for main industrial crops as cotton, rape, peanut and potato. Along with the agricultural structure adjustment and implementation of *The Plan of Area Distribution for Superior Agro-Product*, local governments are incentivized to develop the agricultural mechanization depending on the regional contexts and characteristics, research and disseminate mechanization technologies for local special agro-products, to meet the demand of agriculture production and promote the development of agriculture and rural economy.

The level of "socialized service" of agricultural machinery increased significantly

Agricultural machinery has become the main means for farmers to deal with agricultural production and increase income. Innovative agricultural machinery service organizations, such as agricultural machinery cooperatives, associations and farm machinery leading households, are emerging. By the end of 2014, there were 175,124 service organizations and 42.9 million households providing mechanized farming service with 55.2 million practitioners. Its gross income reached RMB 536 billion with a total revenue of about RMB 210 billion. Since 1996, relevant ministries and agencies in China have jointly launched the so-called "Cross-regional Wheat Harvesting Programme" using combine harvesters, which has sped up the process of market-orientation, specialization and socialization. Cross-regional harvesting service is now covering not only wheat, but also rice, corn, soybean and potato, with much wider scope and larger areas all over the country.

Figure 4 - Agricultural machinery socialized service

The laws and regulations system for agricultural mechanization is sufficient

The tenth meeting of the Standing Committee of the tenth National People's Congress examined and approved *The Law on Promoting Agricultural Mechanization of the People's Republic of China*, which was put into effect on November 1, 2004. It is the first law on promoting agricultural mechanization in China, and it further defined the promotion function of governments at all levels in agricultural mechanization. It also provided the ground for supporting policies to research & development of agricultural machinery, to the system of quality guarantee and service of agricultural machinery, to the application of advanced technology and equipment for farmers and organizations. It launched measure to subsidize and provide financial service for farmers and service providers to purchase machines and equipment, to design and apply policies on preferential tax, fuel subsidies and so on. This law further improved the development environment for agricultural mechanization with a combination of government instruction and market-oriented system under the legal frame. It exerts an active and great influence on the cause of agricultural mechanization while encouraging farmers to purchase and use farm machinery and raise productivity.

International exchange and cooperation has been strengthened

In recent years, China's large market volume has aroused the attention of large international manufacturers of agricultural machinery. They have cooperated with the relevant Chinese departments and enterprises to exploit the market and have also won the market share. In order to encourage the imports of large-size agricultural machinery, Chinese government has promulgated the preferential import tax policies. China's agricultural machinery research institutes, colleges & universities and enterprises are actively strengthening technical innovation and cooperation so as to improve product quality by introducing the foreign advanced experiences and technologies.

THE DEVELOPMENT ENVIRONMENT OF AGRICULTURAL MECHANIZATION

Both national and rural economy have been keeping a constant, stable and rapid development in China. The increased investment in agriculture and rural economy has brought new opportunities for the development of agricultural mechanization, especially when Chinese government pays great attention to food security and farmers' income.

The economic environment

The national economic strength is the economic base for development of agricultural mechanization. In 2014, China per capita GDP reached US $7485, the urbanization rate 54.8%, and the total amount of tax revenue over RMB 10,380 billion. Overall, China has entered the mid-term stage of industrialization when the industry finances agriculture and the city promotes the development of the countryside.

The economic growth in cities and towns has created new conditions for the development of agricultural mechanization. Along with the progress of China's industrialization and modernization, there must be an inexorable trend, in which city brings country into town, rural labour force is transferring to non-agricultural in-

dustries and urban rapidly. The rural migrant labour to business has more than 263 million, 60% of them are under 40 years old. A present, there exists the limited supply of labour force in some developed areas with a big problem of the old aged and large contradiction between the operating labours and farming seasons. Nearly one-third of agricultural labour force are more than 50 years old. Thus it's more urgent to use machinery instead of labour in agricultural production and should change the traditional production method to heighten agricultural productivity greatly by using machinery instead of handwork. Therefore, it will provide new conditions for the development of agricultural mechanization in term of the rural economic progress, the improvement of living quality in country and big transfer of rural labour force.
The establishment of modern agriculture has put forward new demands for agricultural mechanization. China has currently entered a new stage of development in modern agriculture with the change from tradition to modern style. The practice has proved that it is favorable for the progress of agricultural mechanization to enhance scientific and technical standards, to reduce production cost with higher efficiency, to increase output ratio of farmland and productivity and to heighten the integrated production capacity. In addition, some new mechanized technologies, including conservation tillage and straw utilization, can save resource, protect environment and keep sustainable agriculture development. In a word, it is an inevitable choice to realize agricultural mechanization for agricultural modernization.

The policy environment

Chinese government is paying great attention to agriculture, rural areas and farmers, and it promulgated a series of policies to support agriculture production and increase farmers' income sustainably. For example, Chinese central government issued *The Law on Promoting Agricultural Mechanization of the People's Republic of China* in June 2004, which has brought the development of agricultural mechanization into the legally enabled course.
In recent years, both national and local governments in China have adopted a series of measures, such as regional laws and regulations issued by 30 provinces, municipalities or autonomous regions, to support and promote the development of agricultural mechanization. Since 1998, the country has put in place the policy of agricultural machinery purchase subsidy and the central government alone has allocated RMB 23.7 billion to fund these subsidies in 2014 and 2015 (**Figure 5**). This is

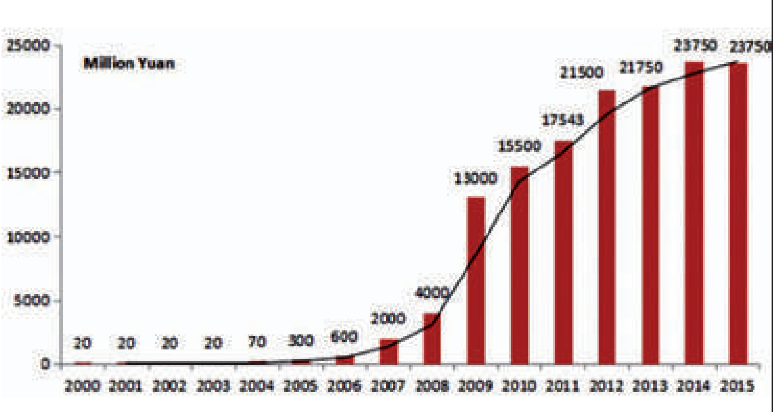

Figure 5 - China central government fund for agricultural machinery purchase subsidies

sometimes supplemented by additional subsidy regimes and incentives at local levels. The measure of subsidy has greatly aroused farmers' and agricultural production organizations' enthusiasm for purchase and use of farm machinery, hence accelerating the popularization and use of new equipment and technology.

The technological environment

There are over 8,000 agricultural machinery manufacturers in China, with over 2000 scale-size enterprises with annual revenue of over RMB 20 million. Chinese enterprises can manufacture about 4,000 kinds of agricultural machinery under 1517 small-types, 120 big-types and 12 categories. The annual farm machinery gross industrial output value ranked the third place in manufacturing sectors and reached RMB 428 billion in 2015 (**Figure 6**), only after automobile and electrical engineering and equipment. This has also laid a proper foundation for the development of agricultural mechanization. China has become a global manufacturing power of agricultural machinery.

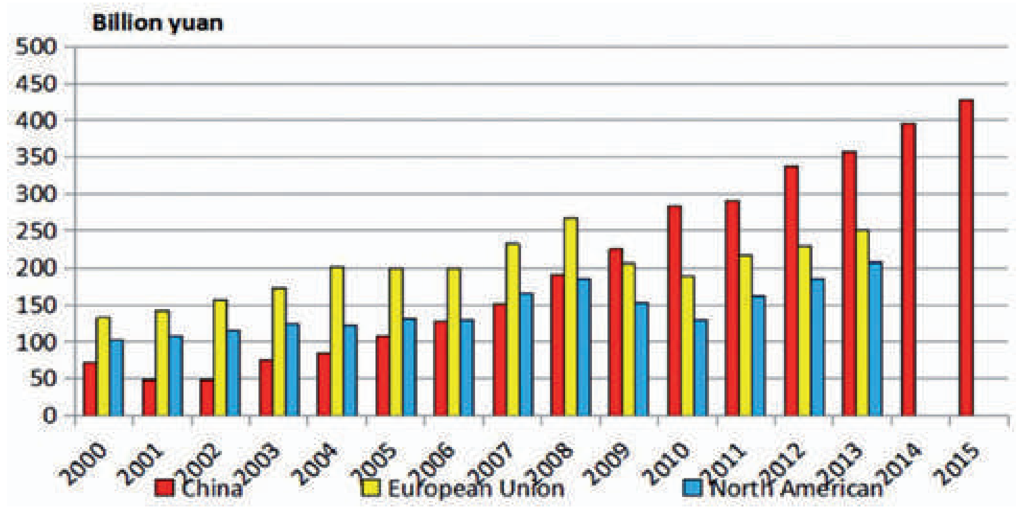

Figure 6 - The gross value of agricultural machinery industrial output from 2000 to 2015

A relatively comprehensive network of management and service of agricultural machinery has come into being. The system consists of various departments and institutions of research, testing and evaluating, extension and training at different levels. There were 77 research institutions and 63 testing and certification bodies over district level, 2570 extension stations and 1736 technical training schools over county level in 2014. Surrounding the service to larger agriculture and the development to larger agricultural machinery, China has set up the platform and demonstration base of technological innovation suitable for agricultural production, and coordinated and facilitated efforts on the research and production of new agricultural machinery and matching implements with marked achievements and transformed capability.

THE DEVELOPMENT TREND OF AGRICULTURAL MECHANIZATION

Agricultural mechanization should provide technological support for the improvement of resources utilization ratio and labouring productivity in term of the global process of international economy and the change of opportunity cost of labour force. The priorities of future agricultural mechanization will be placed at developing resource – and labour – saving technologies, shifting focus from production to higher efficiency, as well as from single technologies to integrated technologies. The role of agriculture will become much more significant to national economy for it to keep high growth rate. The development trend of agricultural mechanization in China can be summarized in four aspects.

The different development patterns of agricultural mechanization will come into being with the closer combination between mechanization and industrialization for production of main agro-products

The key task in agriculture and rural economy is to push the strategic structure adjustment at present. China will fully implement *The Plan of Area Distribution for Superior Agro-Product* and *The national agricultural modernization plan (2016-2020)* to establish the industrial zones of superior agro-products. Agricultural mechanization should provide technical support for industrial development of local superior agricultural areas in accordance with the demand of structure adjustment of agriculture and rural economy so as to improve the international competition. For example, the focus will be put on the mechanization of production, processing and storage of main agro-products on the base of increased mechanization level for the coastal developed areas in East China. In the main production areas of grain, efforts will be focused on increasing the mechanization level of wheat production, further developing mechanization strategy and technology for paddy, corn and potato crops, and providing comprehensive service from before-production to post-harvest. Meanwhile the country will gradually advance mechanization of grain production, and also promote mechanization of pasture and industrial crops as sugar material and cotton, and agro-product processing in West China. The above-mentioned technologies of agricultural mechanization, including for industrial crops, facility agriculture, animal farming and agro-product processing will be the new champions. The development pattern of agricultural mechanization will be characterized by regional diversification, high efficiency and better quality.

Sustainable agricultural mechanization technologies will be the priority

China will carry out the strategy of sustainable development to enhance rational utilization and efficient protection of resources of farmland, water and fertilizer, to improve agricultural ecological environments, to protect agricultural environment from pollution, to promote agricultural transformation from resource intensiveness to sustainability. The key points will be put into the development of advanced and applicable mechanized technologies for the protection of ecological environments and sustainable development. Therefore, China will give priority to the development of technologies mainly including conservation tillage, water-saving irrigation, integrated utilization of agricultural waste materials, intensive farming engineering, grassland improvement and construction of man-made pasture, integrated prevention and control of biological disaster, infrastructure facilities construction, agricultural aviation and so on.

The capacity of agricultural machinery socialized service and the system of laws & regulations of agricultural mechanization will be further improved

The basic development trend of agricultural mechanization is noted for the foundation and improvement of fair and standard market system of agricultural machinery product and service, the promotion of market-orient and industrialization of agricultural machinery service, the wider spread of socialization service and higher increasing of service level. China will further strengthen and improve the development of the related laws & regulations, the standards of agricultural mechanization, the quality control system of agricultural machinery and the information system of agricultural mechanization so as to provide the legal and technical support for the sound development of agricultural mechanization.

The process of technical innovation and upgrading and updating of agricultural machinery product will be accelerated

Along with popularization and extension of modern scientific technology such as advanced manufacturing, mechanical and electrical integration, intelligence and information, the agricultural machinery industry will quicken the pace of technical innovation and product modification, and greatly improve the performance and quality of agricultural equipment, which is beneficial to reduce the difference of agricultural mechanization between China and foreign advanced countries. This will also be conducive to increased international competitiveness for China's agricultural machinery.

CONCLUSIONS

China is a large agricultural country, and its agriculture is strongly connected with agricultural mechanization. Agricultural mechanization can improve agricultural labour productivity and the farmland ecological environment. China's government will increase the support for agricultural mechanization, encourage context-specific development models in different regions, support the application and popularization of agricultural mechanization technologies of energy saving and environmental protection, improve land management, support the development of agricultural cooperatives and family farms so as to reduce the costs and improve the benefits of mechanized systems.

CHAPTER 7

AGRICULTURAL MECHANIZATION IN INDIA

CHAPTER 7
AGRICULTURAL MECHANIZATION IN INDIA

BY **GAJENDRA SINGH** (INDIA), **SURENDRA SINGH** (INDIA)

INTRODUCTION

India is a country with various landforms ranging from lofty mountains to ravines to deltas, also including the high altitude forests of the Himalayas, sprawling grasslands of the Indo-Gangetic plains, peninsular plateaus of South East and South West India, and many other geological formations. The climate of India is full of extremes, and it is the most prone sector to rainfall variations, either deficit or excess, particularly when it coincides with critical crop growth stages. Due to the presence of a wide range of geological and climatic conditions, Indian agriculture is diverse and complex, with both irrigated and dry land areas capable of producing most of the food and horticultural crops of the world. Of the total 329 million ha geographical area of the country, 166 million ha is available for cultivation, and during the last three decades the net sown area has remained around 141 million ha, of which about 65 million ha (46%) is irrigated and the remaining 76 million ha (54%) is rain-fed (http://www.gktoday.in/blog/gross-cropped-area-and-net-cropped-area-in-india/6.3.2016). With increasing levels of industrialization, creation of special economic zones, urbanization and development of housing sector there is a decline in arable land. Rice, wheat, maize, sorghum, and millet are the five main cereals grown in India. Along with these, pulses, oilseeds, cotton, jute, sugarcane, and potato are the other major crops. Pulses include mainly gram (chickpea) and pigeon pea, and oilseeds include mainly groundnut, mustard and rapeseeds, soybean, and sunflower.

Indian agriculture has marked its presence at the global level. India ranks second worldwide in farm output. The economic contribution of agriculture to India's GDP is steadily declining with the country's broad-based economic growth [11]. This is evident from the increasing contribution of services and the manufacturing sectors to the GDP. Agriculture and allied sectors contribute approximately 14% to GDP and 50% of labor force. Service sector contributes 59% to GDP and industry 27% [2]. About 60% of the households are dependent on agriculture. Rapid urbanization and growth of other sectors promising employment is impacting the farm labour availability.

In India, 63% holdings are below 1 ha accounting for 19% of the operated area, while over 86% of holdings are less than 2 ha accounting for nearly 40% of the area. Fragmentation of operational farm holdings is yet another major concern in this respect, and the average size of holdings has shrunk from 2.82 ha in 1971 to 1.15 ha in 2011. India is the second largest producer of wheat and rice and the third largest producer of pulses, sugarcane, roots and tuber crops, vegetables, coconut, dry fruits, agriculture-based textile raw materials, inland fish and eggs [10]. The country produced about 267 million tonnes (Mt) of food grains during 2013-14, surpassing all earlier records. Record production was achieved in the case of rice (104 Mt), wheat (94 Mt), cotton (35 million bales), and sugarcane (358 Mt).

The story of the development of agricultural mechanization in India is both fascinating and in many ways, quite remarkable. The country has moved forward over the past six decades from one that faced severe food shortages to where today it has become an exporter of many food commodities and a major exporter of other industrial products, including agricultural tractors. The first tractor was brought to India in 1914. In the 1930s, pump-sets were introduced in the country. In the 1940s, high horsepower crawler tractors were imported under the aegis of the Central Tractor Organization (CTO), mainly for land development and to eradicate the obnoxious weed *kans* grass. At the time of independence, Indian farmers used mostly bullock-drawn ploughs and wooden planks for pulverization, compaction and smoothening. Hand tools like spades, pick axes, crow-bars, hoes, sickles and choppers were in use. For irrigation, watering buckets and Persian wheels were used, and for transportation it was bullock carts. In the late 1950s, manufacturing of irrigation pump-sets started. There were only about 8,000 tractors in 1950, and these increased to 39,000 units in 1960. Engines (petrol, kerosene, and diesel) were being used for post-harvest processing like floor making, rice milling, grinding, etc. Tractor manufacturing started in 1961 with the production of 880 tractors by Eicher Tractors Ltd. During this decade, five units were licensed to manufacture tractors while production of power tillers started in 1965. Up until the 1970s India continued to import tractors, and in the 1980s, it became a net exporter. During the period 1960-1980, more than 90% of public investment in agriculture was for the development of irrigation facilities, including medium and major irrigation projects. The result was a significant increase in the area under irrigation, particularly in the states of Punjab, Haryana and Uttar Pradesh. During the era of the Green Revolution, provision of a range of inputs such as agro-chemicals and farm machinery contributed towards increasing agricultural productivity. The availability of farm power registered a significant increase due to enhanced contributions from electrical and mechanical sources [7].

Now, mechanization is required in every operation of agricultural production, post-harvest, food processing and rural living. The Indian farmer is adapting to farm mechanization faster than ever. Farmers, policy makers and developmental agencies now realize that for raising farm productivity at reduced unit cost of production, mechanization is essential. With increasing labour wages and agriculture produce market prices, farmers, especially the medium and large ones, are looking for labour-saving devices to remain competitive. As demand for farm mechanization is expanding, mechanization has come to centre stage with the globalization of world markets. The sale of tractors in India, to a greater extent, reflects the level of mechanization. Innovation in the farm machinery sector will drive the next phase of agricultural growth in the country. The Government of India has been encouraging farm mechanization through different policy interventions and schemes.

FARM MECHANIZATION IN INDIA

With a growing agricultural labour shortage in India, a shift to mechanization is a logical response. The agriculture sector value chain includes all the steps from preparation of seedbeds to harvesting, threshing and post-harvest operations. For every step in crop production lifecycles, use of farm implements and machinery enhances man-machine efficiency. Farm mechanization not only reduces labour and time but also reduces losses and cuts down production costs. Mechanization supports the optimal utilization of resources (e.g., land, labour, and water) and expensive farm inputs (seeds, fertilizers, chemicals). Judicious use of time, labour and resources helps facilitate sustainable intensification (multi-cropping) and timely planting of crops, which can give crops more time to mature, leading to increase in productivity. The use of machinery also helps in reducing losses, pollution and drudgery. Farm mechanization, in association

Benefits	Value
Saving in seed	15-20%
Saving in fertilizer	15-20%
Saving in time	20-30%
Reduction in labour	20-30%
Increase in cropping intensity	5-20%
Higher productivity	10-15%

Table 1 - Contribution of agricultural mechanization (Estimated values)

with improved crop inputs, has shown improved yields by 10-15% (**Table 1**). It has been further estimated that the use of proper equipment can increase productivity by up to 30% and reduce cost of cultivation by about 20% [2]. It is evident from **Table 1** that 15-30% savings are experienced in seeds and fertilizers, 20-30% in saving time and labour, and 5-10% in cropping intensity through farm mechanization. There are various benefits to farm mechanization. For instance, it helps in the conversion of uncultivable land to agricultural land through advanced tilling techniques, it decreases the workload on the agricultural work force, and it helps improve the safety of farm operations and encourages youth to join farming to work and live in rural India. The growth in farm mechanization and the investments in machinery and equipment are presented in **Table 2** [7].

Table 2 - Aspects of Indian Agriculture (1960-2010) *[Source: 7]*

Item	1960	1970	1980	1990	2000	2010
Agricultural land (Mha)	133	140	140	143	143	142
Irrigation pumps (million)	0.4	3.3	6.2	12.9	19.5	25
Irrigated area (percent)	19	22	28	33	34	35
Cropping intensity	1.15	1.18	1.23	1.30	1.33	1.39
Fertilizer use (kg/ha)	2	15	39	88	125	150
Grain yield (kg/ha)	700	860	1 000	1 300	1 600	1 900
Tractors (thousands)	37	146	531	1 200	2 600	4 000
Area per tractor (ha)	3 600	960	260	120	55	36
Power tillers (thousand)	0	9.5	16	31	100	155
Draft animals (million)	80.4	82.6	73.4	70.9	60.3	50*

The overall level of Farm Mechanization in India is about 40-45% (i.e. tillage about 40%, seeding and planting about 30%, plant protection about 35-45% and harvesting and threshing about 60-70% for rice and wheat and less than 15% for other crops); **Table 3**. The level of mechanization varies greatly by region. States in the north such as Punjab, Haryana and western Uttar Pradesh have high levels of mechanization (70-80% overall; 80-90% for rice and wheat) due to high productive land, as well as a declining labour force and also full support from state governments. The eastern and southern states have lower levels of mechanization (35-45%) due to smaller and more scattered land holdings. In the north-eastern states, the level of farm mechanization is extremely low, mainly due to hilly topography, high transportation cost, and the socio-economic conditions of the farmers.

In India, farm mechanization played a significant role in pulling the country out of a starving situation (after independence) to a commendable position. Farm mechanization contributed the increase in gross cultivated area (165 M ha in 1965-66 to 195 M ha in 2013-14) and yield (productivity based on net sown area increased from 0.64 t/ha in 1965-66 to 2.15 t/ha in 2014-15) (**Table 4**).

Table 3 - Level of farm mechanization in India (overall mechanization is about 40-45%)

Operation	Percentage
Soil working and seedbed preparation	40
Seeding and planting	30
Plant protection	34
Irrigation	37
Harvesting and threshing	60-70% for wheat and rice and less than 15% for others

Table 4 - Cropping intensity and power availability on Indian farms *[Source: 11]*

Year	Cropping intensity (%)	Food grain productivity (t/ha)	Power available (kW/ha) (*)	Power per unit production (kW/t)	Net sown area per tractor (ha)
1965-66	114.00	0.636	0.32	0.50	2162
1975-76	120.30	0.944	0.48	0.51	487
1985-86	126.80	1.184	0.73	0.62	174
1995-96	130.80	1.499	1.05	0.70	82
2005-06	135.90	1.715	1.49	0.87	45
2010-11	140.50	1.930	1.78	0.92	34
2011-12	141.50	2.079	1.87	0.90	31
2012-13	140.90	2.129	1.94	0.91	29
2013-14	142.00	2.111	2.02	0.96	27
2014-15	142.00	2.150	2.14	1.00	24

Note: * Power per unit area is total power available in million kW divided by total cultivated area (142 million ha)

To adopt higher levels of technology to perform complex operations within time constraints and with comfort and dignity for the operators, mechanical power becomes essential. Thus, the extent of use of mechanical power serves as an indicator of acceptance of higher levels of technology on farms. It is apparent from **Table 4** that the cropping intensity increased with growth in per-unit power availability. It was 114% with power availability of 0.32 kW/ha during 1965-66 that increased to about 142% with an increase in power availability of 2.14 kW/ha in 2014-15. Net sown area per tractor shows the reverse trend during the same period, which was about 2162 ha/tractor in 1965-66 and fell to 24 ha/tractor in 2014-15.

Power availability and productivity relations

The different sources of power available on Indian farms for doing various mobile and stationary operations are mobile power such as human (men, women), draught animals (bullocks, buffaloes, camels, horses and ponies, mules and donkeys), tractors, power tillers and self-propelled machines (combines, dozers, reapers, sprayers etc.), and stationary power i.e. diesel/petrol/kerosene engines (for pump sets, threshers, sprayers and other stationary operations) and electric motors (for pump sets, threshers, sprayers and other stationary operations). Human energy is predominantly used for all operations in agriculture. While the population of agricultural workers as a percentage of rural population has gone down from about 69% in 1951 to about 55% in 2014-15, in absolute terms, due to increase in overall population, the number of agricultural workers available in rural areas increased from 131 million in 1960-61 to 263 million in 2010-11. However, agricultural workers fell to 218 million in 2014-15 and corresponding power increased from 6.55 million kW to 10.9 million kW (**Tables 5 and 6**).

These agricultural workers are engaged in different farm operations and depend on agriculture for their livelihood, even when they are not fully employed throughout the year. Due to too much involvement of labour in different farm operations, the cost of production of many crops in our country is quite high as compared to developed countries. Human power availability for agriculture was about 0.043 kW/ha in 1960-61, which is estimated to be about 0.077 kW/ha in 2014-15 (**Figure 1**). The share of agricultural workers in total power availability in 1960-61 was about 16.3%, which has fallen to 3.6% in 2014-15. This trend is expected to continue in the near future.

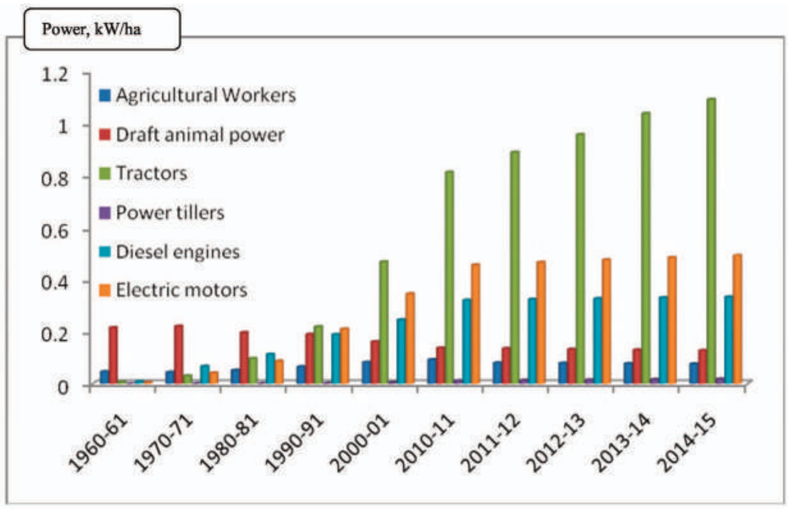

Figure 1 - Power available from different power sources on Indian farms
[Source: 12]

Over the years, the annual use of draught animals has been declining. While earlier, a pair of animals was being used for about 1200-1800 hours annually, their average annual use has now come down to only about 300-500 hours, that too for tillage, sowing, weeding and rural transport. The population of draught animals during 1960-61 to 2013-14 is given in **Table 5**. This declining trend of draught power has been more visible in those states where the demand for tractors and power tillers has been high. It has been observed that on an average a tractor is replacing about 5 pairs of animals and a power tiller is replacing about 2 pairs of animals. The draught animal population, mainly derived from bovines, was 80.4 million in 1960-61, peaked at 82.6 million in 1970-71 and fell to 47.7 million by 2014-15. Share of draught animal power was 76% of the total farm power in 1960-61 and fell to 6% only in 2014-15. Draught animal power availability in India decreased from 0.22 kW/ha in 1960-61 to 0.13 kW/ha by 2014-15 (**Figure 1**). The trend suggests that it will continue to decline in the near future.

For meeting the increased demand of mobile power for timely farm operations and increased intensity of cropping, additional power is available mainly from tractors and power tillers. Self-propelled reapers and combines also provide mobile power, especially for harvesting operations. The tractor population in India has grown from 0.037 million in 1960-61 to 5.946 million units in the year 2014-15 (**Table 5**). Farm power availability from tractors has consequently increased from 0.007 kW/ha in 1960 to 1.09 kW/ha in 2014-15 at an overall growth rate of 10% during the last 55 years (**Figure 1**). Power tillers or two-wheel tractors, came to India with the import of two units from Japan in 1961. There are mainly two manufacturers of power tillers in the country, producing about 6 models in the range of 5.97-8.95 kW (8-12 hp). In addition to these, there are many others that are importing power tillers and selling them in the country. The contribution of tractors and power tillers was only about 2.4% of total farm power in 1960-61, which increased to 52% in 2014-15. Sales of tractors and power tillers has continuously increased during last 50 years and seem to have been stabilizing in recent years (**Figure 2, Table 5**).

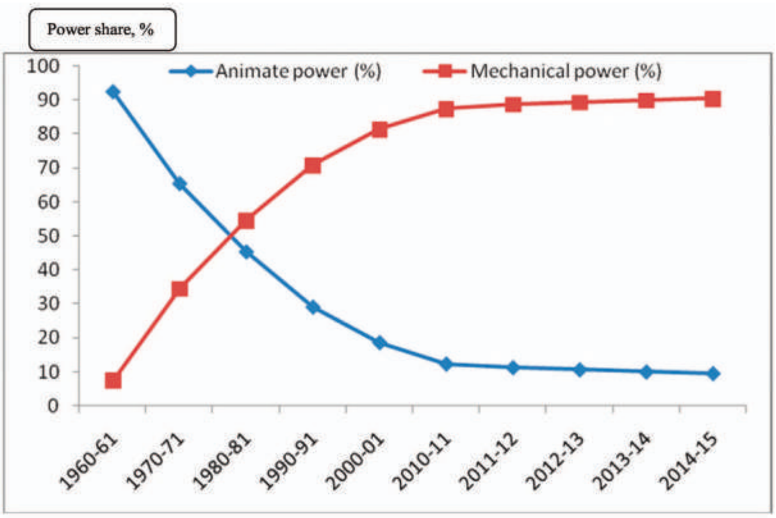

Figure 2 - Animate and mechanical power scenario in Indian agriculture *[Source: 12]*

Table 5 - Farm power sources in India *[Source: 2, 10, 11]*

Year	Population of farm power sources (million)					
	Agricultural Workers	Draft animal power	Tractors	Power tillers	Diesel engines	Electric motors
1960-61	131	80.4	0.037	0	0.23	0.20
1970-71	126	82.6	0.168	0.0096	1.70	1.60
1980-81	148	73.4	0.531	0.0162	2.88	3.35
1990-91	185	70.9	1.192	0.0323	4.80	8.07
2000-01	234	60.3	2.546	0.1147	6.226	13.25
2010-11	263	51.3	4.427	0.2943	8.134	17.488
2011-12	228	50.4	4.843	0.3442	8.212	17.873
2012-13	225	49.5	5.211	0.3801	8.290	18.245
2013-14	221	48.6	5.653	0.4240	8.368	18.606
2014-15	218	47.7	5.946	0.4619	8.446	18.957

Stationary power sources in agriculture comprised mainly of diesel engines and electric motors are used for irrigation equipment, operating threshers and other stationary machines. The populations of these prime movers have increased tremendously since the green revolution in the 1960s (**Table 5**). Farm power from diesel engines increased from 0.009 kW/ha in 1960-61 to 0.333 kW/ha in 2014-15, registering an annual compound growth rate of about 7% during the last 53 years (**Figure 1**). The contribution of diesel engines in total power was about 3% in 1960-61 and increased to 22% in 1990-91, but fell to 15% in 2014-15. The electric motor population increased 95 times between 1960-61 and 2014-15 at an impressive annual compound growth rate of 9% (**Table 5**). Farm power availability consequently increased exponentially from 0.005 kW/ha to 0.494 kW/ha during the same period (**Figure 1**). The contribution of electric motors in total power was about 2% in 1960-61 and increased to 24% in 1990-91, but fell to 23% in 2014-15.

The extent of mechanical power use serves as an indicator of acceptance of higher levels of technology on farms. Over the years, the shift has been towards the use of mechanical and electrical sources of power, and in 1960-61 about 93% farm power was coming from animate sources (**Figure 2**). In 2014-15 the contribution of animate sources of power fell to about 10% and that of mechanical and electrical sources of power increased from 7% in 1960-61 to about 90%. The relationship between food grains productivity and unit farm power availability for the period 1960-61 to 2014-15 was estimated by linear function, with a highly significant value of coefficient of determination (R^2), (**Figure 3**). This indicates that over the range used, productivity and unit power availability have a linear relationship. It is also evident that farm power input has to be increased further to achieve higher food grains production. The composition of farm power from different sources has to be properly balanced to meet timely requirements for various farm operations.

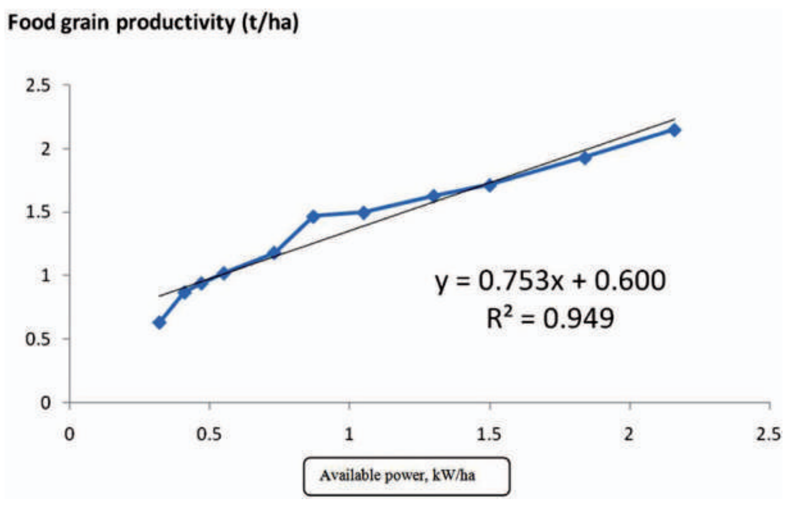

Figure 3 - Food grain productivity and power availability relationship in Indian agriculture
[Source: 12]

The total power availability on Indian farms has increased from 0.32 to 2.14 kW/ha during 1965-66 to 2014-15. The overall mechanization level in India is only 40-45%, even though 90% of the total farm power is contributed by mechanical and electrical power sources. One of the major constraints of increasing agricultural production and productivity is the inadequacy of farm power and machinery with the farmers. The average farm power availability needs to be increased to a minimum of 2.5 kW/ha by 2020 to assure timeliness and quality in field operations, and to undertake heavy field operations like sub-soiling, chiselling, deep ploughing and summer ploughing. The concerted efforts have resulted in the mechanization of critical farm operations of major crops in different states. The economic benefit of adoption of improved implements is of the order of US$ 125 billion per annum, which is only a small fraction of the existing potential for improvement [8]. This has also resulted in generating employment for rural youth and artisans for the production, operation and maintenance of these machines. Due to a significant and continuous reduction of the workforce in agriculture, higher levels of farm mechanization are necessary for sustainable productivity and profitability.

Table 6 - Power available from different sources in India *[Source: 10, 11, 13]*

Year	Power available from different power sources (million kW*)						Total power Million kW
	Agricultural Workers	Draft animal power	Tractors	Power tillers	Diesel engines	Electric motors	
1960-61	6.55	30.552	0.966	0	1.288	0.74	40.126
1970-71	6.30	31.388	4.385	0.054	9.520	5.92	57.567
1980-81	7.40	27.892	13.859	0.091	16.128	12.395	77.765
1990-91	9.25	26.942	31.111	0.181	26.880	29.859	124.223
2000-01	11.70	22.914	66.451	0.642	34.866	49.025	185.598
2010-11	13.15	19.494	115.545	1.648	45.550	64.706	260.093
2011-12	11.40	19.152	126.402	1.928	45.987	66.130	270.999
2012-13	11.25	18.810	136.007	2.129	46.424	67.506	282.126
2013-14	11.05	18.468	147.543	2.374	46.861	68.842	295.138
2014-15	10.90	18.126	155.191	2.587	47.298	70.141	304.243

Note: 1 Human= 0.05 kW; draught animal = 0.38 kW; tractor = 26.1 kW; Power tiller = 5.6 kW; Electric motor = 3.7 kW; Diesel Engine = 5.6 kW
* Power per unit area is total power available in million kW divided by total cultivated area (142 million ha)

Status of tractor sales

Monsoon rains play a key role in sales of tractors. A series of good or bad monsoon rains can affect the sales. In recent years, the industry has registered a good growth in sales, both domestic as well as exports. This is also partly because of the government initiative to boost up agriculture and agricultural machinery industry. In India, it has been to increase use of tractors, while farm mechanization in the sense of small machinery has been under-tapped. However, the scenario is changing now. In terms of number of units, the Indian tractor industry is the largest in the world and accounts for one third of global production. The sales of tractors have grown at a CAGR of 11% from 247,351 in 2004-05 to 571,249 in 2015-16 [4, 12, 13]; (**Figure 4**). Similar is the trend for power tillers (**Figure 4**). The power tiller market is dominated by two Indian companies collectively sharing more than 65% of the market. The remaining market is mainly covered by small firms importing power tillers from China. The Indian power tiller manufacturers also export to the Middle East, Russia, Turkey, European Union and other parts of Asia and Africa.

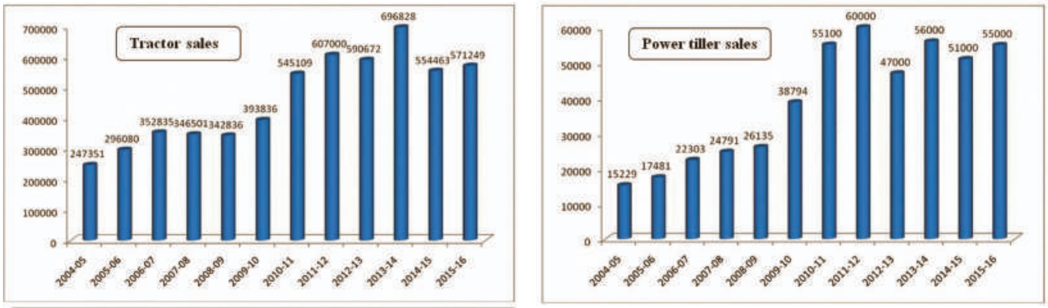

Figure 4 - Tractor and power tiller sales data for last 11 years *[Source: 4, 5, 11, 13, 14*

Manufacturers	hp range	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16
VST	< 20 hp	3752	4602	7219	7901	7637	6948	7801
ESCORTS		-	-	-	-	110	344	653
Mahindra & Mahindra Group		-	-	-	9551	12989	13545	12407
TAFE Group		-	-	-	919	46	-	-
SONALIKA		-	-	-	357	2562	4227	2745
Total		3752	4602	7219	18728	23344	25064	23606
FORCE Motors	21-30 hp	211	499	1118	955	2171	2737	3243
ESCORTS		8887	8953	8532	1766	440	247	405
HMT		695	541	349	465	129	91	62
Mahindra & Mahindra Group		32121	37558	45402	8419	22277	17393	14282
TAFE Group		19701	19999	23067	21093	18206	13449	9703
SONALIKA		3281	1885	1949	3105	1936	2209	3477
Total		64896		80417	35803	45159	36126	31172
FORCE Motors	31-40 hp	283	269	380	308	408	380	429
ESCORTS		19041	20032	19243	25580	32590	28856	20458
HMT		3373	3168	2791	1284	1025	807	507
Mahindra &Mahindra Group		83921	102853	104327	89144	91828	77728	72223
TAFE Group		61701	70528	93828	80398	67892	60829	54548
John Deere		5917	7418	8810	5946	7612	5418	4920
New Holland		5118	5803	5874	6390	6269	7027	5793
SAME DEUTZ-FAHR		345	240	108	88	28	7	84
SONALIKA		17983	21177	34979	24559	25031	26542	23115
Total		197682		270340	233697	232683	207594	182077
FORCE Motors	41-50 hp	122	329	384	389	680	1016	1101
ESCORTS		28890	37054	34782	30416	35056	26051	21806
HMT		373	458	665	373	204	122	106
Mahindra & Mahindra Group		28023	40790	47654	90462	140377	114774	104281
TAFE Group		13495	19239	26754	35773	79677	67411	58911
John Deere		10839	16440	19240	15824	25748	19089	16928
New Holland		16215	27091	30179	19565	20170	18187	15560
SAME DEUTZ-FAHR		1052	1160	1078	1209	1193	1014	979
SONALIKA		6833	12997	14746	17115	20980	25784	24452
Total		105842	155558	175482	211126	324085	273448	244124
ESCORTS	> 51 hp	0	0	0	1651	2401	4149	2257
HMT		211	643	621	401	188	107	58
Mahindra &Mahindra Group		27268	37329	49610	25024	11819	12986	12229
TAFE Group		2966	4321	6781	5008	7552	8465	8144
John Deere		21101	29714	32739	19629	18321	20160	26929
SAME DEUTZ-FAHR		2020	4340	5744	3853	4596	9130	8299
SONALIKA		7469	10967	10943	14794	16567	18690	14415
New Holland		0	0	0	8976	10086	11039	10408
Total		**61035**	**87314**	**106438**	**79336**	**71530**	**84726**	**82739**

Table 7 - Horsepower tractor sales by different manufacturers *[Source: 10, 14]*

Manufacturers	Share in production (%)						
	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16
M&M Group	39.55	39.84	38.60	38.47	40.08	37.72	37.71
TAFE Group	22.59	20.80	23.51	24.73	24.88	23.96	22.99
ESCORTS	13.12	12.04	9.78	10.27	10.13	9.55	9.00
Sonalika	8.21	8.58	9.79	10.35	0.83	12.36	11.94
John Deere	8.74	9.77	9.50	7.15	9.63	7.40	8.92
New Holland	4.92	6.00	5.63	6.04	7.42	5.80	5.56
SAME DEUTZ-FAHR	0.79	1.05	1.08	0.89	5.24	1.36	1.55
VST	0.87	0.84	1.13	1.37	1.10	1.01	1.37
HMT	1.07	0.88	0.69	0.44	0.22	0.18	0.13
FORCE Motors	0.14	0.20	0.29	0.29	0.47	0.66	0.83

Table 8 - Leading tractor manufacturers during the last five years (2009-10 to 2013-14) *[Source: 10]*

Among all the tractor manufacturers in the country, the top five manufacturers in sales of tractors during the last five years were the Mahindra & Mahindra group, TAFE group, Escorts, Sonalika and John Deere (**Tables 7 and 8**). These five manufacturers constituted more than 90% of total tractors sold during the period 2009-10 to 2012-13 and about 85% in 2015-16. Mahindra & Mahindra group ranked first with about 40% of the total tractors sold as far as the individual manufacturer is concerned. The shares of other manufacturers were TAFE group (22-25%), Escorts (10-13%), Sonalika (8-10%) and John Deere (7-10%) of the total number of tractors sold during the period of five years. The share of other manufacturers namely New Holland, SAME DEUTZ-FAHR, VST, HMT and Force Motors together contributed 9 -15% of the total tractors sold during the period of 2009-10 to 2015-16. Horsepower-wise, tractors sold by different manufacturers were also analyzed (**Table 7**). In the range of < 20 hp, Mahindra & Mahindra Group ranked first followed by VST and Sonalika during 2015-16. In the range of 21-30 hp, Mahindra & Mahindra group again registered first rank, followed by TAFE group and Sonalika. Mahindra & Mahindra group again ranked first with over 72,000 units sold, followed by TAFE group, Escorts and Sonalika during 2015-16 in the 31-40 hp range. The range of 41-50 hp tractors were the most preferred in 2015-16, in which Mahindra & Mahindra group stood first,

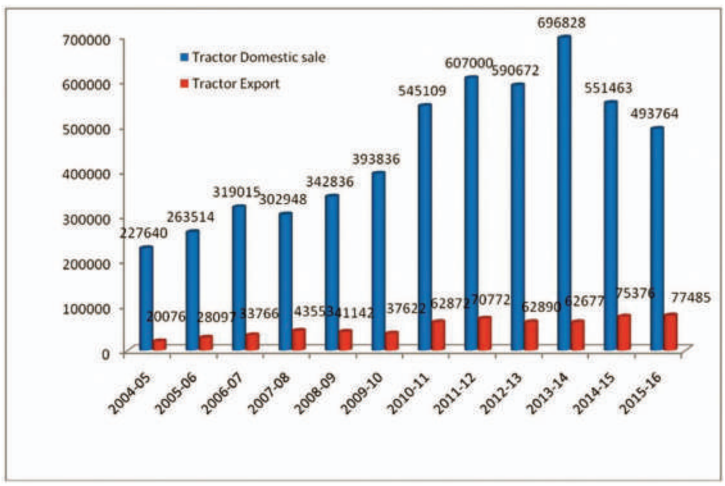

Figure 5 - Export and domestic sales of tractors
[Source: 12]

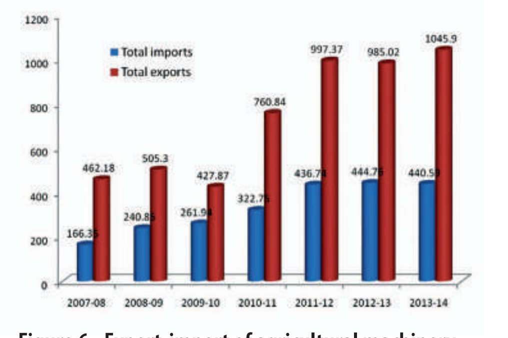

Figure 6 - Export-import of agricultural machinery (US$ million) *[Source: 4]*

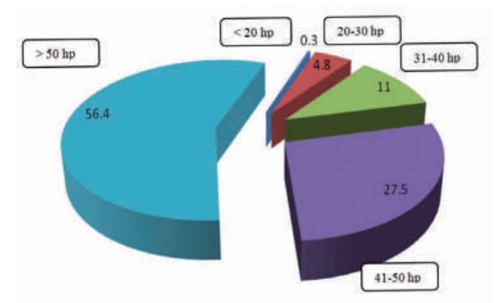

Figure 7 - Percent share of tractor's export in different hp range *[Source: 2]*

followed by TAFE group, Escorts, Sonalika and John Deere. In the high hp range >50 hp, John Deere ranked first, followed by Sonalika, Mahindra & Mahindra group and New Holland for the year 2015-16.

Export of tractors started in 1980, and by 2003-04 exports were about 5,000 units (more than 2% of total sales). It has been observed that about 8 to 10% of tractors are exported every year since 2003-04 (**Figure 5**). Export of agricultural machinery including tractors and power tillers was higher than import during 2007-08 to 2014-15 (**Figure 6**). The export trend of tractors during the period 2007-08 to 2014-15 was also analysed (**Figure 6**). Total export of agricultural machinery including tractors and power tillers during 2013-14 was US$ 1045.9 million, whereas import was US$ 440.59 million. The current trend of export of different ranges of tractors (**Figure7**) showed that the demand for the high hp range of tractors (above 51 hp) was highest (56.4%) followed by the 41-50 hp range (27.5%), 31-40 hp range (11%), 21-30 hp (4.8%) and less than 20 hp (0.3%) of the total tractor export. Domestic sale trends revealed a continuous increase during the last ten years (**Figure 5**). Domestic sales during 2004-05 were 2,27,640 units, increased to 5,45,109 units during 2010-11 and registered CAGR of 12.20%. The rising sales trend was again maintained up to 2013-14 with 6,96,828 units and shown a CAGR of 7.13% during the overall period of 2004-05 to 2013-14. Tractors are exported to mostly the USA, China, Australia, Latin America, the Middle East and South Asia.

Status of farm tools and equipment in Indian agriculture

Amidst growing concerns about manpower availability and shrinking profitability of agriculture as a business, the need has been felt for appropriate, affordable and energy efficient equipment and technology for the cost-effective production and processing of crops focused at increased yield, reduced cost of cultivation, prevention of losses and value addition through location specific management practices. The farmers have realized these advantages, and mechanization is undergoing an upward trend in many parts of the country. However, the type of equipment suitable for cultivation and the rate of introduction of new equipment are to be considered with a multidisciplinary approach specific to the site needs. During the past four decades a large number of farm tools, implements and machines have been developed for different farm operations, such

Farm Machinery	Number of farm machines available ('000)				
	1992-93	2003-04	% Increase over 1992-93	2013-14	% Increase over 2003-04
Manual Operated Machinery					
Sprayer	1827	2046	12.0	2214	8.2
Animal Operated Machinery					
Wooden plough	43464	44267	1.8	44997	1.6
Steel plough	12649	19622	55.0	25972	32.4
Seed drill/ Seed-cum-fertilizer drill	472	963	104.0	1474	53.1
Wet land puddler	5151	8550	39.7	11640	36.1
Animal cart	15220	16577	8.9	17663	6.5
Tractor/power operated machinery					
Power operated sprayer/duster	303	561	85.1	796	41.9
MB Plough	408	852	108.8	1328	55.9
Cultivator	706	949	34.4	1170	23.3
Disc harrow	531	913	71.9	1260	38.0
Seed cum fertilizer drill	390	1011	159.2	2852	182.1
Planter	54	75	38.9	92	22.7
Leveler	1057	1827	72.8	2343	28.2
Thresher/Multi crop thresher	2597	5309	104.4	7775	46.4
Combines (Both tractor-drawn and self-propelled)	8.5	20	135.3	59	195.0

Table 9 - Population of farm machines in India *[Source: 15]*

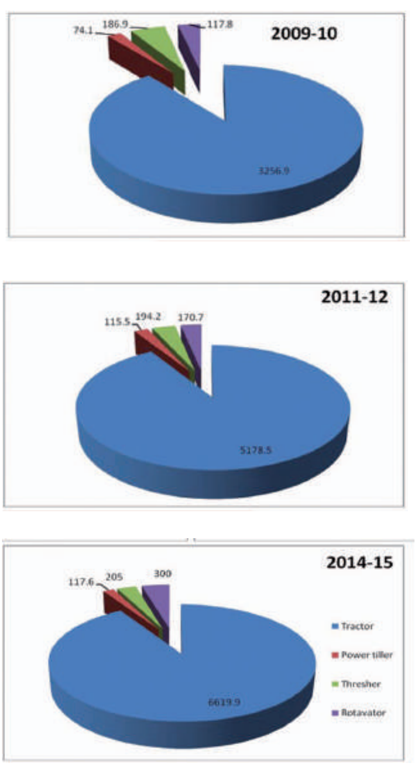

Figure 8 - Market share of different farm equipment (US$ million)
[Source: 2]

as land levelling, seed bed preparation, sowing and planting, weeding and hoeing, plant protection, harvesting, threshing, de-husking, decorticating, etc (**Table 9**).

The total investment in the farm machines in 2005 was estimated to be around Rs 273 billion (US$ 6 billion). This compares to an annual investment in 1997 of about Rs 180 billion (US$ 5 billion) [6]. Annual investment in 2005 in agro-processing and post-harvest equipment was estimated to be around Rs 200 billion, bringing the total annual investment to Rs 453 billion or US$ 10 billion (IASRI, 2006).

The agricultural machinery market is estimated to grow at a CAGR of over 10% in future. The market for threshers (multi-crop and paddy), rotavators, planters and zero-till drills in India is highly disorganized and is dominated by a large number of small and medium scale enterprises (SMEs) mostly located in the states of Punjab, Haryana, Uttar Pradesh, Bihar, Madhya Pradesh, Gujarat, Maharashtra, Tamil Nadu and Andhra Pradesh. Market share of tractors has been highest and it was of the order of US$ 3256.9 million in 2009-10 and increased to US$ 6619.9 million in 2014-15 (**Figure 8**). Similarly, the market share of threshers was US$ 186.9 million in 2009-10 and increased to US$ 205 million in 2014-15; that of rotavators was US$ 117.8 million in 2009-10 and increased to US$ 300 million in 2014-15. The high rate of subsidies, up to 50%, provided by the government is expected to encourage large numbers of farmers to purchase farm equipment in coming years.

The scenario of farm mechanization has certainly changed as the Indian agricultural equipment market has experienced a rapid growth with expected strong potential for future growth as well. There has been a surge in demand over the past few years for tractors, power tillers, combine harvesters, rotavators, threshers and rice transplanters. The current annual market for tractors is 450,000 – 500,000 and power tillers 50,000 – 60,000 units (**Table 10**). The combine harvesters market is estimated at 3,500-4,000 units annually. It is estimated that the annual requirement for rotavators, threshers and power weeders is 100,000 – 120,000; 60,000-75,000; and 35,000 – 40,000, respectively. The sales of machinery like MB ploughs (45,000 – 50,000), laser guided land levellers (2,500- 3,500) and planters (15,000 – 25,000) are growing fast for custom hiring purposes even though prices are high, since the demand is high. Given the constraint of limited days for usage of machinery, the operational and capital costs may be optimized for the farmers by making the machinery available on custom hiring. Thus, even small farmers are able to get the benefit of agricultural mechanization. Setting up custom hiring services will be able to provide the machinery on a need basis to small and medium farmers.

Item	Numbers	Item	Numbers
Tractors	450000 - 500000	Power tillers	50000 – 60000
MB plow	45000 - 50000	Rotavator	100000 – 120000
Cultivators	150000 - 200000	Harrows	120000 – 150000
Seed-ferti drills	60000 - 75000	Planters	15000 – 25000
Rice transplanters	2000 - 3000	Power weeders	35000 – 40000
Reapers	10000 - 15000	Threshers	60000 – 75000
Combine harvesters	3500 - 4000	Trailers	150000 – 175000
Sprayers (TD)	10000 - 15000	Laser land levellers	2500 – 3500
Potato diggers	25000 - 30000	Rotary hoes/Power weeders	20000 – 25000

Table 10 - Annual market of major farm machinery used in India *[Source: 12]*

The large scale manufacturers have dealer networks at a district/sub-district level. Some customers have direct retail options, but this is true only with very large manufacturers such as for tractors. These retail outlets sometimes work as franchises. Financing remains a key hurdle for farmers accessing the subsidies extended by the Government. Even with subsidy support, farmers have limited options. Even some farm equipment manufacturers provide financial assistance to the farmers. Farmers also have the option of approaching Cooperative Banks for assistance. Agricultural loans are also available to farmers for seeds, fertilizers, chemicals, machinery through public sector banks in India. The State Bank of India as well as other nationalized banks offers a variety of schemes to help farmers in the purchase of farm equipment. Although the farmers have a number of options for financing, there are many hurdles such as high interest rates, relatively low repayment periods (5-7 years) and high collaterals.

MAJOR THRUST TOWARDS AGRICULTURAL MECHANIZATION IN 12TH PLAN

There is no Agricultural Mechanization Policy as such in India. In order to lay special emphasis on farm mechanization and to bring more inclusiveness, a dedicated Sub-Mission on Agricultural Mechanization (SMAM) for the XII Plan (2012-17) has been launched by the Government of India [1, 4]. SMAM puts "Small and Marginal Farmers" at the core of the interventions with a special emphasis on "reaching the unreached", i.e. bringing farm mechanization to those villages where the technologies deployed are decades old. Besides, the mission is also catering to "adverse economies of scale" by promoting "Custom Hiring Services" through "the rural entrepreneurship" model. The Mission is catalysing an accelerated but inclusive growth of agricultural mechanization and providing assistance for promoting and strengthening agricultural mechanization through training, testing and demonstration; Post-harvest technology and management; Procurement of selected agricultural machinery and equipment; Establishment of farm machinery banks for custom hiring; Establishing hi-tech productive equipment centres to target low productive agricultural regions and assistance for increasing farm mechanization. To make the cost of machinery affordable and to make it available to all farmers, the government has launched a credit-linked subsidy scheme for the establishment of farm machinery banks and hi-tech high productive equipment hubs for custom hiring for increasing the reach of farm mechanization to small and marginal farmers and to the regions where availability of farm power is low.

In India, the presence of a large number of non-banking financial corporations has encouraged farmers to buy agricultural machinery on credit. Of the entire machinery, tractors have the highest share in the overall sales. These accounted for about 66% share in total agricultural machinery sold in 2013. Farm Machinery Banks are promoting mechanization in districts with low farm power availability, facilitating hiring services of various agricultural machinery/implements used for different farm operations, expanding mechanized activities during cropping seasons in large areas especially in small and marginal holdings, and introducing improved/newly developed agricultural implements and machines in crop production. Hi-Tech, High Productive Equipment Hubs are promoting utilization of hi-tech, high value machines for higher productivity, providing hiring services for various high value crop specific machines applied for different operations, expanding mechanized activities during cropping seasons to cover large areas, and involving manufacturers for setting up such centres.

The Government of India is witnessing some key challenges in the 12th five-year plan, such as distribution of subsidies, inadequate mechanization, shortage of labour and youth participation in agriculture. The Government is aiming to increase the growth of the agriculture sector through implementation of farm mechanization programmes in the country through schemes such as Rashtriya Krishi Vikash Yojana (RKVY); Mission on Integrated Development of Horticulture (MIDH); National Mission on Oilseeds and Oil Palm (NMOOP); National

Food Security Mission (NFSM); National Mission on Agricultural Extension & Technology (NMAET) and lately Sub-Mission on Agricultural Mechanization (SMAM). Subsidies to the tune of 25-50% are being made available to the farmers to ensure availability of farm machines and equipment at reasonable prices. However, ceiling limits are applicable to different categories of farmers for various machines (**Table 11**). In addition to this 10%, additional assistance is allocated for women beneficiaries to procure agricultural machinery by the Government through a number of other schemes.

Type of Agricultural Machinery	For SC, ST, Small & Marginal farmers, Women and NE States beneficiary		For other beneficiary	
	Maximum Permissible subsidy per Machine/ Equipment per beneficiary	Pattern of Assistance	Maximum Permissible subsidy per Machine/ Equipment per beneficiary	Pattern of Assistance
Tractors				
(i) Tractor (08-15 PTO HP)	Rs. 1.00 lakh	35%	Rs. 0.75 lakh	25%
(ii) Tractor (15 -20 PTO HP)	Rs. 1.00 lakh	35%	Rs. 0.75 lakh	25%
(iii) Tractor (Above 20-40 PTO HP)	Rs. 1.25 lakh	35%	Rs. 1.00 lakh	25%
(iv) Tractor (40-70 PTO HP)	Rs. 1.25 lakh	35%	Rs. 1.00 lakh	25%
Power Tillers				
(i) Power Tiller (below 8 BHP)	Rs. 0.50 lakh	50%	Rs. 0.40 lakh.	40%
(ii) Power Tiller (8 BHP & above)	Rs. 0.75 lakh	50%	Rs. 0.60 lakh.	40%
Rice Transplanter				
Self-Propelled Rice Transplanter (4 rows)	Rs.0.94 lakh	50%	Rs. 0.75 lakh	40%
Self Propelled Rice Transplanter (i) above 4-8 rows (ii) above 8-16 rows	Rs. 2.0 lakh.	40%	Rs. 2.0 lakh.	40%
Self Propelled Machinery				
Self-Propelled Machinery (i) Reaper cum Binder	Rs. 1.25 lakh	50%	Rs. 1.00 lakh	40%
Specialized Self Propelled Machinery (i) Reaper (ii) Post Hole Digger/Augur (iii) Pneumatic/ other Planter	Rs. 0.63 lakh	50%	Rs. 0.50 lakh	40%
Self-Propelled Horticultural Machinery (i) Fruit Plucker (ii) Tree pruners (iii) Fruit Harvesters (iv) Fruit Graders (v) Track Trolley (vi) Nursery Media Filling Machine (vii) Multipurpose Hydraulic System (viii) Power operated horticulture tools for pruning, budding, grating, shearing etc.	Rs. 1.25 lakh	50%	Rs. 1.00 lakh	40%

Table 11- Subsidy given to the farmers on tractors and other agricultural machinery
[Source: 1]

CUSTOM HIRING SERVICES

The transformation of the mechanization scenario is inevitable. The challenge is to manage the gradual and evolutionary transformation with minimum social costs. The investment capacity of the majority of the farmers is poor. These farmers cannot own expensive farm power units and machinery. However, they are making use of modern technology like combine harvesters, tillage equipment and planting/sowing machinery through custom hiring. This has helped them to improve the timeliness of operations, to increase land productivity and increase economic returns. States like Punjab and Haryana have set examples by establishing "Custom Hiring Centres". Diversification of agriculture, need for and introduction of new machines and the trend among the farmers to use increasingly larger tractors will vastly expand the scope for custom hiring of farm equipment as multi-farm use will help to keep the operating cost of farm equipment at a reasonable level.

A Custom Hiring Centre is a unit comprising a set of farm implements and machinery for hiring by farmers/users. These centres give farm equipment to farmers/users on a rental basis. The machines available at Custom Hiring Centres include tractors, power tillers, combines and all other machines required for land levelling, seed bed preparing to harvesting and threshing and post-harvest activities such as winnowing etc. The Government of India also recognizes these centres and the role they play in mechanizing farm operations. As a result, the establishment of Farm Machinery Banks for custom hiring is one of the important components of the Sub-Mission on Agricultural Mechanization (SMAM). The government also provides financial assistance to establish these banks.

It is a well-known fact that each operation in agriculture, right from seed bed preparation to harvesting, requires a specific agriculture machine or implements. Due to poor economic status, many farmers are not able to purchase newly developed implements even at subsidized prices. Keeping this in view, the Government provides tractors with matching implements, power tillers, reapers, threshers etc. to the farmers on custom hiring [7, 9, 13]. Hence the new scheme for the Establishment of Agri-Clinic and Agri-Business Centres under RKVY has been taken up. Different states have different custom hiring models and some of these are; (i) Zamindara Farm Solutions, Fazilka (Punjab); (ii) Tarai Development Corporation, Pantnagar (Uttarakhand); (iii) Low Cost Farm Machinery Centre, Gulbarga (Karnataka);(iv) ICAR-Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad (Telangana); (v) Indian Society for Agriculture Professionals (ISAP), New Delhi; (vi) Tata Chemicals Ltd, Noida and Smart-Krishi, Aligarh (U.P.); (vii) CIMMYT Custom Hiring of Farm Machinery, Begusarai (Bihar); (viii) Women self-help group (SHG) in Kerala; (ix) Individual Entrepreneurs in Odisha; (x) Farmers' Cooperative Society in Punjab; (xi) "Yantra Doot Villages" of Madhya Pradesh; (xii) Panchayat level Custom Hiring Centres in Bihar; (xiii) Dharmasthala Trust to run Custom Hire Centres, Karnataka. The following issues emerged from different custom hiring models that need further attention for wider adoption:

- extension workers are the key persons in technology transfer. They need not only interpersonal communication skills, but also technical qualifications. With a very limited number of extension staff for a large number of client-farmers, the result would likely end up in non-adoption of some technologies. Besides, these workers might be lacking the capability to integrate the mechanization technology into the total farming system. They too might be lacking in training particularly dealing with agricultural mechanization;

- Tthe lack of support services to ensure the machine's acceptability to farmers has been a continuing constraint in promoting agricultural machinery. These include limited access to credit, and ineffective marketing systems;
- Iintroduction of improved tools/implements and promoting custom hiring centres require not only huge initial investments but also a large number of trained manpower in the operation and maintenance of the agricultural machines. Training and building the skills of local youth, and traditional and village-based smiths is another issue that needs attention. This is not only desirable but very necessary to integrate the indigenous talent in the huge rural market.

FUTURE PROSPECTS FOR MECHANIZATION AND SUGGESTED POLICY

The future investment in agricultural mechanization will be guided by a number of factors. Sales data gathered over the past years indicates a growing preference for tractors in the 41 to 50 hp or higher hp range. High capacity machines will also be preferred in the future, including rotary tillers, harrows, laser levellers, high clearance sprayers, planters, high capacity threshers and self-propelled and tractor-towed combines. The custom hiring of mechanical power for tillage, irrigation, harvesting and threshing will be preferred by those farmers who cannot afford to own machines. The present trend in agricultural mechanization is for the high capacity machines to be used for custom hiring and for contracted field operations. Hand operated tools and implements will only grow very slowly as the number of agricultural workers increases. Animal operated implements will decrease due to the continued decrease in the number of draught animals. In contrast, the use of power operated farm equipment will increase rapidly.

Business and enterprise-friendly policies, laws, and regulations as well as physical and institutional infrastructures, which encourage commercial activities and entrepreneurship in farming, input supply, produce handling, processing and marketing as well as in manufacturing will be key factors in the success of agricultural mechanization in the different states of India. For this:

1. reduce or eliminate subsidies and use these funds to reduce interest rates on loans and taxes for the purchase of equipment and machinery for agricultural operations and food processing;
2. invest in infrastructure, mainly, roads, electricity supply, irrigation systems and markets with storage and processing facilities in catchment areas;
3. provide assured support prices for the farmers' produce;
4. strengthen support services for research and development; testing and standards; as well as for human resources development in support of agricultural mechanization.

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CHAPTER 8

AGRICULTURAL MECHANIZATION IN AFRICA

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AGRICULTURAL MECHANIZATION IN AFRICA

BY **BASSAM SNOBAR** (JORDAN), **BRIAN SIMS** (UK), **JOSEF KIENZLE** (FAO), **JOSEPH MPAGALILE** (FAO)

BACKGROUND TO THE AGRICULTURAL SECTOR

As Africa is the world's second largest continent, it can be difficult to deal with it as a whole because of the wide diversity across its different countries. A few are fairly well developed, but the majority are still developing. Within the continent, there is a noticeable difference in the degree of agricultural development between North Africa (NA) and sub-Saharan Africa (SSA) (see **Table 1**). A United Nations definition of NA includes seven countries lying north of the Saharan Desert (Algeria, Egypt, Libya, Morocco, Sudan, Tunisia and Western Sahara).

Compared Items	Africa	North Africa
Population:		
Total (2012) (billion)	1.07	0.17
Rural (% of total) (2011)	60%	44.8%
Agricultural (% of total)(2012)	49.3%	23.5%
Total GDP current US$ (2012) (trillion)	1.928	0.666
Agricultural Land (% of total) (2011)	37.9%	17.6%
Forest Land (% of total) (2011)	22.0%	1.4%
Arable Agricultural Area (2011)	19.8%	19.1%
Permanent Crops (% of total) (2011)	2.6%	2.8%
Crop Land per Capita (ha/cap) (2011)	0.24	0.17
Fertilizer consumption/ha of arable land and permanent crops (kg/ha) (2011):		
Nitrogen	13.26	40.59
Phosphate	9.11	34.43
Potash	1.63	1.96
Agricultural R&D spending (2008) **2005 ppp (Purchasing Power Parity) US$ (billion)**	2.324	0.576
Prevalence of: (2011-13)		
Undernourishment	21.2%	2.1%
ood Inadequacy	27.0%	4.9%
Value of food production (US$/cap)	179	246
Arable land equipped for irrigation (2009-11) **cereal import dependency ratio**	6% 30%	26% 50%
Population at Risk of Drought, Floods & Extra Temperature (2009)	1.5%	0
Cereal Yield (t/ha) (2011)	1.48	2.91
Coarse Grain Yield (t/ha) (2011)	1.25	2.44
Pulse Yield (t/ha) (2011)	0.62	1.18

Table 1 - Comparisons of population and agricultural data for all of Africa and North Africa
[Source: 13]

THE AFRICAN AGRICULTURAL SECTOR

Africa has a large population (1.1. billion) with a majority in rural areas, where most are engaged in agricultural production. However, both the rural and agricultural populations are decreasing (**Figure 1**); the agricultural job market has declined from about 1/3 of total employment in 1990 to about 1/4 in 2014 (**Figure 2**).
The African continent is potentially rich in agricultural land, amounting to about 38% of the total area [13], and this could be expanded. The arable area represents about 20% of the total agricultural area, the continent's harvested area equates to 10% of the world total [13], and this has the potential to be increased.

Figure 1 - Proportion of the rural(1) and agricultural(2) populations of the total in Africa
[Sources: (1) 13; (2) 14]

Figure 2 - Employment in Agriculture for Africa and the World for 1990 and 2014
[Source: 14]

In 1961, Africa had 5.3% of the world total irrigated land area, and this had dropped to 4.8% in 2003 [27]. The annual renewable freshwater supply (5.56 trillion m^3) [28] is reasonable and should be used to expand the irrigated areas. Africa's irrigated arable land is 5% of the total, compared to 38% in nine developing countries (Bangladesh, Brazil, China, India, Pakistan, Philippines, Republic of Korea, Thailand and Viet Nam) [17]. Many regions of Africa are sandy and arid, which makes them less suitable for agricultural production on any sustainable scale [20]. FAO & ITPS (2015) report that soil degradation is one of the root causes of the stagnating and declining agricultural productivity in SSA. The four types of soil change that pose major threats are: soil erosion, soil organic matter decline, soil nutrient depletion, and loss of soil biological diversity. They conclude that soil degradation is a great threat to the ecosystem services in SSA, particularly sustainable food production and security. In the case of NA and the Near East, the soils are nearly completely hyper-arid, arid or semi-arid, and the degradation of natural resources in arable lands is considered as one of the main threats to agricultural production in all countries in the region.

Africa's GDP, based on a "Purchasing Power Parity" valuation, is USD 5.43 trillion; the largest national figure is for Nigeria at 1.06 trillion, and the smallest is Comoros at 122 million [13].The GDP per capita based on a Purchasing Power Parity valuation is USD 4,826 [14]; the largest is Equatorial Guinea (USD 32,557) and the smallest is Central African Republic (USD 607). African GDP per capita is very low compared to world figures; it could and should be increased by, for example, investing in and expanding the agricultural sector. Currently, the value addition in the agricultural sector supply chain is very low when compared to other regions. With sound mechanization investments, it can be doubled or tripled. Along the agricultural product value chain, the added value is 4% for Africa compared to 14% for the world [13].

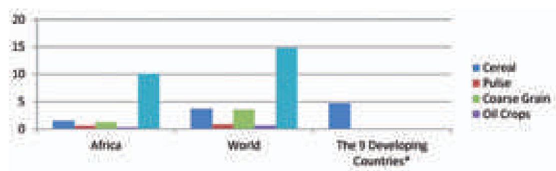

Figure 3 - Comparisons between yields (t/ha) of different crops in Africa and the World
*[Source: 13, *Bangladesh, Brazil, China, India, Pakistan, Philippines, Republic of Korea, Thailand and Viet Nam]*

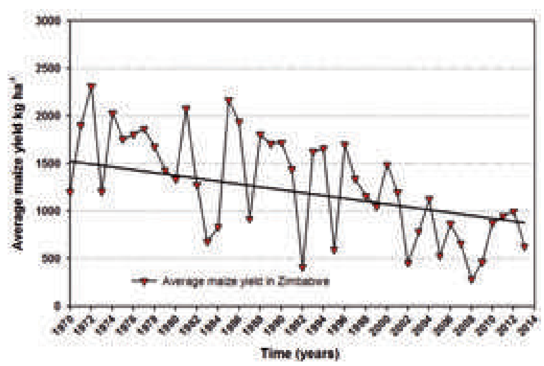

Figure 4 - Average maize grain yields in Zimbabwe (1970-2014)
[Source: adapted from 34]

The prevalence of undernourishment is 19.8% for Africa compared to 10.8% for the World [14]. The value of food production in Africa is USD 202.2 billion, representing 9% of the total world food production value [14]. The yields of major crops are significantly lower than those of the world (**Figure 3**). The cereal yields are extremely low compared to the nine developing countries mentioned above. Yields of maize in Zimbabwe are also continuing to a decline (**Figure 4**). Figure 4 is a graphic illustration of how maize yields are falling as a result of, *inter alia*, the impact of soil degradation, overgrazing, and climate change. The reason for such low yields is attributed to the extremely low rate of fertilizer use (**Figures 5 and 6**) and low rates of irrigation and mechanization.

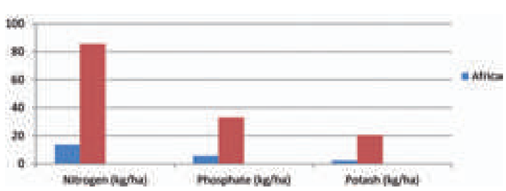

Figure 5 - Africa's fertilizer use compared with world consumption
[Source: 14]

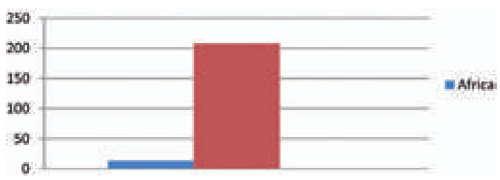

Figure 6 - Comparisons of Africa's fertilizer use(kg/ha) with that of 9 developing countries*
*[Source: 17,.*Bangladesh, Brazil, China, India, Pakistan, Phillippines, Republic of Korea, Thailand,Viet Nam]*

In 2014, Africa's share of food imports was 7.2% of total world imports while its export was 2.9% of total world food exports [14]. In 2014 the continent had a huge net trade deficit of cereals (USD 28.75 billion), which was more than four times the world net trade deficit for this commodity.

THE STATUS OF AGRICULTURAL MACHINERY IN AFRICA

The use of farm machinery in agriculture in the African continent in general, and in SSA in particular, is at a low level compared to other continents. However, NA countries enjoy higher levels of farm mechanization than SSA. The number of tractors per 1000 hectares in SSA is 28 compared to 241 in the nine developing countries listed above [17]. The growth of tractor numbers between 1961 and 2000 in SSA is 28% compared to 500% in Asia, 469% in Latin America and Caribbean and 1350% in the Near East and NA (**Figure 7**).

Figure 7 - Growth in tractor numbers between 1961 and 2000 for sub-Saharan Africa (SSA) and other regions
[Source: 17]

The ratio of farm power source utilization in SSA is 65% manual, 25% animal and 10% engine compared to 25% manual, 25% animal and 50% engine in three developing regions (Asia, Near East and North Africa, and Latin America and Caribbean).The use of tractors (especially in SSA) is very low compared to other regions (including the Near East and North Africa regions).

THE NEED FOR IMPROVED AGRICULTURAL MECHANIZATION SUPPLY

Applying more power per hectare to agricultural production will not necessarily result in increased output either in terms of quantity or quality. Mechanization, as is the case with all other agricultural inputs, must be applied judiciously and with specific, planned-for, results in mind. Mechanization has the potential to achieve the following:

- increasing land and labour productivity;
- improving timeliness of operations;
- reducing drudgery;

- mechanization along the value chain;
- promoting modernization and commercialization of the small-scale farming sector;
- improving productivity whilst conserving natural resources – sustainable crop production intensification.

Increasing labour productivity

As early as 1975, Giles [18] had shown that agricultural productivity is positively correlated with farm power use throughout the world, including developing countries. In a study specifically focused on SSA, Bishop-Sambrook [8] reviewed the mechanization inputs available to 14 communities in 7 countries. She observed that, in East Africa, the loss of cattle (used for animal traction) through disease, drought, distress sale or theft had undermined the livelihood strategies for the whole community and had contributed to a drastic decline in agricultural production. Hoe cultivation had become the norm, resulting in smaller areas under cultivation (i.e. resulting in lower labour productivity), reduced total output, reduced cash cropping, increased food insecurity, reduced farm incomes and a higher incidence of poverty. In West Africa, the loss of tractor-hire services in the communities studied had been tempered by substituting hired labour for tractors. The sustainability of this strategy will depend on the continued availability of hired labour at affordable prices. Bishop-Sambrook concludes that farm power technologies, other than the hoe, gain considerable advantages in terms of area cultivated, crop diversity, yields, reduced levels of drudgery, opportunities to redeploy family labour, and household food security. While hoe households typically cultivate 1-2 ha per year, draught animal power (DAP) hirers cultivate 2 ha, households owning DAP cultivate 3-4 ha, tractor hirers cultivate about 8 ha, and households owning tractors cultivate more than 20 ha. In a more recent study of small-scale farm power mechanization in African agriculture, van Eerdewijk & Danielsen [35] looked specifically at gender issues associated with the demand for farm power. They indicated that the farming activities that women consider as contributing to their labour burden include: weeding, tillage and land preparation, post-harvest management and transport of agricultural produce. Women consider all tasks where they have to rely solely on their own muscle power (such as weeding, fodder collection or transport of produce carried on their own backs) or hand-tools (e.g. for threshing and grinding) as highly labour-intensive. Across sites in Kenya and Ethiopia, hiring labour and the use of DAP were the most common ways to reduce labour burdens.

Figure 8 - Hand-weeding a groundnut crop is both laborious and time-consuming *[Photo:David O'Neill]*

A detailed study in Uganda [2] found that in the sorghum crop, hand weeding took

Figure 9 - Crop weeding with draught animal power greatly increases labour productivity *[Photo:Brian Sims]*

158 person-hours per hectare compared to 35 h/ha with DAP. These savings in labour reduced weeding costs dramatically from over 50% of total crop production costs to 13% with DAP. **Figures 8 and 9** allow an appreciation of the improvement in labour productivity made possible by the application of additional power in the form of draught animals.
It is clear that farm power and machinery can greatly ease the output of farm labour. Legg *et al*. [22] put the importance of farm power into perspective by suggesting that a hand-hoe equipped farmer can grow enough food for three people, with DAP this can rise to six additional mouths, and with tractor power each farmer can produce food for fifty other people. There is a very wide range of simple technologies that can be manufactured locally which can ease the work load, reduce drudgery, and allow people to increase their output with less energy expenditure. Examples include: ergonometrically superior hand tools (especially hand-hoes), weed control with sprayers, and low-cost carts for human, animal and motorized power sources.

Increasing land productivity

The availability of more farm power means that more land can be cultivated to produce a greater output of crops. However, cultivating more land may not be an option for a smallholder farmer wishing to emerge from near-subsistence production, if the potential for expansion is not readily accessible. In Africa as a whole, there is an area estimated at 600 million hectares of uncultivated arable land representing around 60 percent of the world's available crop land [24]. A large part of this – the Guinea Savannah region – has 400 million ha of land waiting to be developed (along the lines of the *Cerrado* region in Brazil) by the application of the necessary technology, including mechanization (World Bank, 2009), but this macro option may not be open to individual farmers wishing to expand, especially those living in higher population density countries.
Other options to increase land productivity include:

Multi-cropping

Where rainfall and/or irrigation permit, producing multiple crops per year on the same plot of land will raise the overall productivity of the land. Mechanization can play a vital role in facilitating multi-cropping through increasing the speed and efficiency of harvesting one crop and ensuring that the land is prepared for the next crop to be established as soon as possible. Increasing the available power will speed up the land preparation process. To "plough" a hectare by hand-hoe can take up to 60 person-days, a job that might be accomplished with DAP in, say, 3-4 days and by a small tractor in 2-4 hours. Crop harvesting can be greatly speeded up with mechanization. Cassava, for example, can be lifted by a tractor-mounted blade in a mere fraction of the time taken by arduous manual lifting [3]. And in China the rice harvesting system comprising a two-wheel tractor-operated reaper plus thresher plus cleaner is being replaced by combine harvesters which accomplish all three tasks in one pass. One of the outstanding ways to reduce the turn-around time between harvesting one crop and establishing the next is through the adoption of no-till or direct-seeding.

Precision agriculture

Carefully designed machines are capable of improving crop production, and consequently land productivity through accurate placement and precise application. Examples include precision planters capable of placing seeds at precisely the right depth and spacing, and at the same time placing fertilizer alongside and below the crop line. Precision agriculture more generally has opened the door to crop (and animal) management systems that allow inputs to be precisely applied where they will maximize returns and keep costs to a minimum. Input use efficiency is optimized, environmental pollution is minimized, and profitability is increased.

Controlled traffic farming

Soil degradation, especially through erosion and compaction, is disappointingly prevalent throughout the African continent [20]. Degraded, compacted soils lose productivity. One particularly promising mechanization development is controlling the traffic on agricultural soils by means of controlled-traffic farming (CTF). CTF is a way of reducing vehicle (or animal) compaction from the area where the crop is actually grown and confining the wheels (or hooves) to distinct and permanent traffic lines. In CTF systems, all implements (planters, sprayers, combines, etc.) have a particular span, or a multiple of it [5].

Permanent raised beds with residue retention

A similar concept, with similar goals, is the use of permanent raised beds with residue retention for crop production, preferably also combined with conservation agriculture. Developed at the International Centre for Maize and Wheat Improvement (CIMMYT), permanent raised beds have been shown to be a sustainable production alternative to conventional tillage, with its associated high cost, both in rainfed and irrigated agriculture [19, 31]. Not only are yields improved but there are also marked savings in irrigation water use (of around 30%) when compared with flat-planted crops.

Improving timeliness

Insufficient farm power, especially at critical times of the cropping season, can lead to delayed operations with consequent yield penalties. Especially important in this case are the operations of crop establishment, weeding, crop care and harvesting. Crops planted outside the permissible planting window will incur increasingly drastic yield penalties, which can exceed 1% for each additional day's delay (e.g. [21]). Controlling weeds early in the season is crucial to achieve maximum yields. Weeds compete with the crop for light,

Figure 10 - Crop yields can be severely depleted if weeding is not effected on time *[Photo: Jim Ellis-Jones]*

water and nutrients and will limit crop yields if they are allowed to interfere with crop canopy establishment. Late or ineffective weeding can reduce yields to zero in the worst case scenario and is usually the result of a scarcity of labour (farm power) at critical times (**Figure 10**). Planting crops in lines and using draught animal powered weeders can have a dramatic effect on timeliness of the weeding operation and, consequently, on crop yields [2]. The precise timing of crop-care chemical application is of fundamental importance, not only to control the pest, disease or weed infestation that is the target, but also to ensure that the investment in agrochemicals and the application is not wasted.

Field losses occurring as pre-harvest losses are, of course, dependent on the type of crop. Grain crops are particularly susceptible, whilst it may be possible to leave many tuber and root crops in the ground to be harvested when demand justifies it. In the case of grain and legume crops, losses due to delayed harvest can be the result of lodging, seed drop and predation from wildlife (especially birds such as the red-billed quelea (*Quelea quelea*) in Africa). In the US, losses per day of delay in harvest from the optimum date have been calculated, and for maize the timeliness factor is 0.3% per day. Clearly speedy harvest at the optimum time is a requirement to reduce pre-harvest losses and mechanized harvesting is the most logical choice.

Reducing drudgery

The drudgery associated with manual-powered traditional smallholder agriculture is a major reason driving young, able-bodied males into the urban sector in search of more rewarding work prospects. This process is ongoing and we can expect that 70% of the developing countries' population will be in the urban sector by 2050; compared with 50% now [21]. This leaves the elderly, children and women on the farm and it is their muscles that must provide the farm power necessary for crop and animal production. The increasing feminization of the smallholder agriculture sector means that attention to drudgery reduction becomes even more critical. Reducing drudgery can be viewed as a way to increase labour productivity by permitting human energy to be more effectively converted into useful work.

If other power sources (particularly DAP, but also engine power) are not available then a logical approach is to consider whether hand-tools can be made more ergonomically efficient. Radwin [29] considers that a tool is "ergonomic" if it:

- improves the performance and productivity of the operator and the quality of work;
- reduces or eliminates the discomfort, fatigue and stress felt by the operator;
- is designed to reduce the incidence of accidents or injuries;
- is designed in way that does not diminish *any* of the above.

Mechanization along the value chain

The conventional focus of farm mechanization has been on crop production, but more recently the horizon has been expanded to cover the value chain from input supply through crop establishment to harvesting, storage, processing and marketing. Breuer *et al.* [4] graphically represent the concept as can be seen in **Figure 11**.

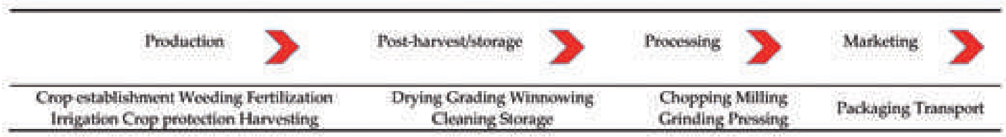

Figure 11 - The potential for mechanization along the agricultural production value chain *[Source: 4]*

By taking a holistic view and considering mechanization opportunities along the value chain, job creation and value addition usually follow. An important aspect of the improvement of value chain mechanization is the facilitation of credit facilities to enable new and improved mechanization inputs to be purchased (**Figure 12**). Yaregal [38] emphasized this point in the context of rice production in Ethiopia, where improvements to the value chain from production through processing, marketing and policy-making were considered by all stakeholders. It is not surprising to find that when all stakeholders work together on a mutually agreed and mutually beneficial development plan, a successful outcome is practically assured.

Figure 12 - Investment in a maize mill for local services can increase product value within the community and provide employment opportunities *[Photo: Brian Sims]*

The issue of access to finance for critical input purchase is touched on by Ndiame [26]. Generally the value of produce rises along the chain from primary production through processing to marketing. At the same time the level of risk varies along the chain, being low at the input supply and processing stages, and peaking at the crop production mechanization "ecosystem" stage. This helps to explain the frequently cited reluctance of financial institutions to finance smallholder crop production operations due to the unacceptable level of risk [7]. **Figure 13** illustrates the situation. The implications for investments in mechanization inputs for high risk operations (such as crop production) are that smallholders are likely to be reluctant to invest heavily in this area. For this reason cooperative group own-

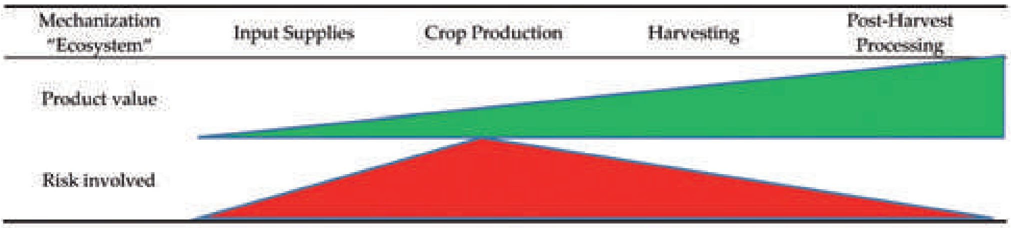

Figure 13 - Product value and risk levels along the agricultural produce value chain *[Source: 26]*

ership or specialist custom-hire services are likely to be the preferred options to deliver mechanization to this farming sector [32]. FAO [11] adds further detail to the potential of the cassava value chain for producers, processors, packagers and transporters, especially in relation to the production of high quality cassava flour.

Sustainability of production

The need for increased food production is clear as the world population heads towards 9 billion by 2050 and migration to urban centres means that there are increasingly fewer people left in the farming sector to produce food for all. More farm power and mechanization are going to be required. At the same time, we should be acutely aware that inappropriate mechanization can degrade soils and can be the cause of accelerated deforestation as more land is brought into production to increase output levels. Consequently, with finite land resources to produce more food, production intensification is a pressing, and on-going, necessity.

We have seen how inappropriate mechanization can, and does, cause soil degradation (especially compaction) and erosion. However, at the same time we have access to mechanization inputs to practise an agriculture that specifically conserves and nurtures natural resources, especially soil and water. The Food and Agriculture Organization of the United Nations (FAO) brings the twin needs of intensification and conservation into focus with the concept of sustainable production intensification (SPI). At the heart of SPI are ideas that say sustainability in soils needs to be conserved by eliminating the damage caused by tillage by means of direct sowing methods. Soil surfaces exposed to rain and wind are prone to erosion so they need to be kept covered with organic matter, either through growing crops and cover crops and/or through residue retention. Organic soil cover also conserves soil moisture and serves as a feed-stock for soil biota. Soil nutrient supply is enhanced by organic matter decomposition and also by widening the diversity of crops through rotations, associations and sequences – especially through the inclusion of legumes in the cropping cycle. Practised together, these conservation practices have been shown to not only conserve natural resources, but increase cropping indices and boost crop yields over time. FAO has encapsulated the SPI concept in its "*Save and Grow*" book [10], which has been followed by more specific "*Save and Grow*" books on cassava [11] and maize, rice and wheat [15].

The particular mechanization needed to enable CA to be implemented includes: direct planters and seed drills; weed control methods including biological ones (with cover crops), mechanical (manual pulling, slashing, knife rolling and surface scraping) and the judicious use of herbicides when necessary; and crop harvesting methods such as stripper headers and straw spreaders on combines. One important aspect of CA systems is that, without energy-intensive soil tillage, the power requirement is greatly reduced. In general terms the power needed for crop production can be halved. This means that smallholder farmers are able to expand the area under crop production and eliminate the need for the contract hire of costly and damaging 4WT-powered tillage operations. Theodor Friedrich gives more detail on the mechanization implications for CA in Sims *et al*. [32].

THE WAY FORWARD AND PROPOSED ACTIONS

Increasing land productivity (a sensitive and limited option even in Africa)

African countries need to look seriously into available options that could be used to increase overall agricultural productivity based on the land which is currently under agricultural production. It is important to explore ways of increasing land productivity despite its sensitivity.

The current agricultural production practices are, to a large extent, contributing to poor land productivity by reducing the ability of the soil to recycle nutrients. In addition, some harvesting practices used by farmers lead to an almost total removal of the residues from the field, which completely breaks down the cycle. According to Jones *et al*. [20], soil degradation including soil erosion, chemical and physical damage affects 65% of the African farmlands. Furthermore, Kienzle and Sims [21] noted that one of the factors that have led to this situation is the continuous use of plough or hand hoe, which leads to soil degradation due to the creation of plough or hoe-pans in the soil profile. Therefore, it is necessary to support farmers to access technologies that would help them enhance land productivity in a sustainable way – following FAO's *Save & Grow* guidelines [10]. Those technologies should be complemented with other good practices such as integrated pest management (IPM), integrated pest and plant nutrient management (IPNM), biodiversity/genetic resources management, system of rice intensification (SRI), and sustainable mechanization.

Promotion and eventual use of conservation technologies by farmers would help to ensure that the prevalent soil degradation resulting from the lack of recycled nitrogen (N_2), phosphorus (P), and carbon (C) and other nutrients, caused by the removal of crop residues, is improved. However, for this to be realized, the issue of the availability of mechanization equipment suitable for conservation agriculture (CA) based farming systems needs to be addressed. Experience shows that it will be difficult to achieve a wider adoption of technologies such as CA if the associated mechanization equipment is not available.

In semi-arid areas where crop residues are used to feed livestock, the land is left uncovered for the whole duration of the dry season leading to further soil degradation. In such scenarios the introduction of CA is challenging, and efforts to keep the soil covered for as long as possible should be combined with the prevention of overgrazing. The gravity of this situation is amplified by the changing climate whereby rains are becoming scarcer, more erratic, and delayed, leaving the soil bare, scorched, and exposed to erosive forces.

Sustainable mechanization also plays a significant role in ensuring that the use of resources such as water and energy during crop production is done more efficiently and is a contribution to climate-smart agriculture approaches. It is important to ensure that energy efficient irrigation pumps associated with climate-proof irrigation structures are used and that an environment is created for participation from the private sector in the manufacturing, distribution, service and repair of such non-tillage equipment.

Increasing labour productivity and soil fertility through sustainable crop intensification

Actions should be taken to ensure that African farmers are able to access and use appropriate agricultural inputs to increase their levels of production. This is necessary since, although there is an urgent need to increase agricultural productivity in SSA, it will be extremely difficult for the labour productivity to increase if farmers do not have access to sustainable technologies, tools, equipment and machinery.

Effort is required to support farmers to access agricultural equipment, which could be useful in increasing their labour productivity and soil fertility. Agricultural mehanization equipment should play a key role in field operations such as preparation of land for production, seed drilling, harvesting, etc. and should enable sustainable practices such as CA. The use of mechanization should aim at increasing crop production per unit area while at the same time following sustainable crop intensification practices, which will result in farm families benefiting from associated and connected socio-economic and environmental improvements. Tillage operations should be reduced to a minimum or be avoided, and external inputs such as plant nutrients (particularly inorganic sources) should be applied optimally and in ways and quantities that do not interfere with or disrupt the biological processes. On the contrary, if farmers continue to use the hand hoe in the traditional soil-degrading manner, it will be very difficult to increase land productivity and soil fertility on African smallholder farms.

Moreover, the availability of mechanization equipment as well as after sales services and spare parts at the right time and and at an affordable price should be supported by public sector enabling policies. This is a challenge in many African countries. Support should also be provided to encourage the local manufacture of appropriate agricultural machinery. This would enhance both availability and compatibility with local conditions, especially for smallholder family-based crop production systems. Mainly for economic reasons, it is understood that not all farmers in Africa are presently able to acquire agricultural machinery, equipment and tools which could enhance their labour productivity. In this case, it is important that hire-services should also be promoted. Under this arrangement, a few better-off farmers or entrepreneurs could own tractors and appropriate agricultural machinery, and provide services to other farmers within their localities. In order for this arrangement to be successful it would be necessary to identify successful hire service models and adapt them to the local environment.

Using mechanization innovations to make cropping systems more climate resilient (sustaining yields)

Agricultural mechanization has the potential to contribute positively to increased agricultural productivity in Africa. However, efforts to promote agricultural mechanization in order to make cropping systems more climate-resilient are faced with multiple hurdles. This situation, therefore, calls for more innovation in supporting farmers to use more sustainable agricultural mechanization in the quest to achieve climate-smart agriculture:

1) *Developing innovative solutions to support farmers:* It is important to support farmers and mechanization service providers in Africa to access agricultural mechanization equipment; particularly those with limited financial means. Governments, working in close collaboration with the private sector, need to put concrete plans in place to support farmers' access to mechanization equipment through different approaches, such as creating links with financial institutions to enable farmers and service providers to access the financial services (especially credit on affordable terms) that they require. Such support should also target socially and economically disadvantaged farmers. Currently, it is extremely difficult for smallholder farmers in Africa to access such services and there are few financial institutions targeting them with relevant financial packages.
2) Parallel efforts are required to support African manufacturers and dealers of agricultural mechanization equipment to facilitate local manufacturing, and make it an attractive business proposition to stock good quality mechanization equipment of the type recommended for climate-smart agriculture. Some of the technologies which could be targeted have been discussed in the preceding sections and they include multi-cropping, precision agriculture, controlled traffic farming, and permanent raised beds with residue retention.
3) *Capacity building:* Many farmers, operators and owners of farm machinery and equipment in the smallholder and emerging farmer sectors of Africa lack key skills that are necessary to enable them to realize the full benefits of mechanization and mechanization services. For example, the proper servicing and maintenance of agricultural mechanization equipment continues to be a major challenge in many African countries, especially in SSA. This has contributed to the poor utilization and poor management of agricultural machinery that has resulted in its accelerated deterioration, preventing farmers and owners from obtaining the full benefit. As a result, it will be important to build capacity through the training of farmers, service providers and operators of agricultural machinery on both technical and sustainable agricultural mechanization matters. Training programmes will also need to address the subject of service provision as a sustainable business for individual entrepreneurs wishing to embark on the provision of mechanization services to smallholder farmers.
4) *Public-Private Links:*The involvement of the private sector in sustainable agricultural mechanization strategies (SAMS) in Africa is vital and needs to be emphasized. SAMS is a planning strategy that contributes to agricultural sustainability, while meeting food self-sufficiency, generating economic development and inclusive growth as well as social benefits (Rolle, 2013). It is part of the enabling environment for the development of sustainable production systems and for the effective use of sustainable agricultural mechanization. The private sector should be supported to take a leading role in disseminating agricultural mechanization equipment, related technologies and services to the agri-

cultural sector value and supply chains, strengthening the supply of services, spare parts and after-sales support. On the other hand, the public sector should continue to play its key roles, especially in creating a environment conducive to supporting the development of SAMS. The public sector should ensure that SAMS in the African countries address the interests of key stakeholders; especially including women and youth. In addition, the weaker areas of access to agricultural mechanization services should be developed and strategies to develop them identified. The public sector also has a role to play in ensuring that standards are in place to ensure that agricultural equipment, whether nationally manufactured and imported, is of good quality and meets all relevant safety standards.

5) Another important area is the provision of support to enable the private sector in Africa to participate in the manufacturing of agricultural equipment for both primary production and agro-processing, with an emphasis on equipment for climate-smart agriculture. In the late seventies and early eighties, several SSA government-sponsored businesses were manufacturing agricultural equipment (mainly manual and animal drawn). That role is no longer played by the governments and therefore should be taken up by the private sector.
6) *Conservation Agriculture:* The role of mechanization is crucial to the promotion and practice of CA in Africa. CA and other resource-conserving and sustainable practices have been applied in several countries in Africa, where both success and challenges have been observed. Despite the challenges which have been reported, there is a good scope for the technology being applied in other countries. For example, according to the World Bank, CA in countries like Zambia has had a significant impact on yields, which have doubled for maize and increased by 60% for cotton [37]. Furthermore, it is important to address those challenges which have been encountered while scaling up the use of the CA technologies in Africa. The need for promotion of CA in Africa calls for countries to develop strategies to stimulate the use of CA using the experience gained so far. Such strategies could include the following key aspects:
   - capacity building, including training in technical and business management skills of farmers, operators, service providers and input suppliers as well as extension officers;
   - pilot projects to act as a learning and promotional platform to demonstrate how climate-smart technologies work and how they could be used to increase production and resilience to drought and other climatic phenomena. In this context, the mutual support offered by the "Farmer Field Schools" group action could be employed to encourage investigation and adoption;
   - creating an attractive and enabling business environment to encourage and support private sector participation in ensuring timely availability of the right equipment.
7) *Using mechanization equipment to reduce post-harvest losses:* Post-harvest losses mean that resources that were used to produce crops, especially water and energy, are lost as well. Currently, it is estimated that one third of the produced food goes to waste. In Africa, a significant proportion of crops is lost after harvest due to weaknesses in crop handling systems. Agricultural mechanization equipment, designed specifically for post-harvest handling, including threshers, graders, mills, vari-

ous processing technologies, bagging and the cold storage chain, have the potential to contribute to a reduction of food losses. Proper introduction of this equipment, however, is necessary, especially to ensure that its use is profitable and sustainable.

8) *Documentation of the lessons learnt:* This should aim at documenting both the negative and the positive lessons learnt over the years across the continent. As the knowledge is compiled, it will be important to cluster it by region where useful comparisons can be made, based on the similarities of farming systems and public sector policy regimes. Such a database would enable countries to understand what has worked well and what have been the major challenges. For example, the issue of underutilization of agricultural mechanization equipment from production to post-harvest handling seems to be a challenge in many countries in SSA. A study conducted in Tanzania [25] revealed that agri-food processing equipment utilization rates are as low as 30% of capacity. At this low utilization rate, it is very difficult for the owners to realize the potential benefits of owning such equipment. Sharing experiences on how such challenges are addressed would be extremely useful.
9) A neutral platform for the compilation, management and dissemination of such a database could be the Food and Agriculture Organization of the United Nations (FAO), which has a longstanding interest in the concept of sustainable agricultural mechanization.
10) *Organizing farmers into groups and networks:* It is also becoming clear that it is important to assist farmers to organize into mutual-interest groups and cooperatives. Individual farmers operating alone face many difficulties in accessing finances, technical support and extension services. Once farmers have organized themselves into groups, cooperatives, and networks, they will be able to access technical, business and finance services. FAO has facilitated the formation of sustainable mechanization across agri-food chain networks (SMAACNET) in Asia.

CONCLUSIONS

Agricultural mechanization policies and strategies

The main purpose of formulating a sustainable agricultural mechanization strategy (SAMS) is to create an environment in which agricultural mechanization will develop from the existing situation to a desired and improved future state. The strategy development process should, wherever possible, be participatory, holistic and sustainable in the widest sense (economically, socially and environmentally). The SAMS is formulated paying specific attention to the roles of both government and the private sector. The output is a suite of policy and institutional recommendations, supported by programmes and by projects, as and when appropriate [9, 12]. There are commonly three stages in formulation of a SAMS.

1) analysis of the present situation, including existing farming systems, current levels of farm power utilization, the state of the agricultural machinery industry (if there is any), institutions supporting the agricultural sector economy and the policy environment. Additionally, an agronomic overview of potential environmental threats such as soil erosion may have to be looked into;

2) development of future scenarios: development of the national economy, implications for agriculture, developments in farming systems, farm power and equipment requirements for sustainable mechanization options and implications for the agricultural machinery industry;
3) the actual strategy framework: define the roles of government and private sector policy and institutional recommendations, design (and finance) subsequent programmes and projects.

Private Public Partnerships for mechanization development

Africa has a history of a strong public sector (Government via Ministries of Agriculture) leadership on mechanization development. Interventions have included a top-down focus on the entire agricultural mechanization scenario. Procurement, mechanization services and spares supply have all been in the realm of the public sector. Over the years, differences in the priorities, perspectives and approaches between the public and private sector towards the development of agricultural mechanization have led to misunderstandings and, consequently, insignificant participation of the private sector in mechanization initiatives in many countries. In the long run, this approach was not sustainable as important stakeholders such as private sector agri-machinery suppliers, manufacturers and service providers were neglected.

Initiatives for applying sustainable mechanization to the development of agricultural production and other functions and activities within the food system require new thinking and perspectives. There is a primary need to see mechanization in a wider and more holistic context. There are numerous cross-cutting and cross-sectorial factors that can contribute to well-functioning, inclusive and sustainable mechanization systems. These need to be ascertained, assessed and elaborated, and the important experiences and lessons learnt shared with wider audiences that can facilitate and enable a more holistic framework to support the design, formulation and implementation of targeted sustainable mechanization policies.

There is a secondary need, that of considering mechanization as an important component of private sector development, but with an acceptance that private sector initiatives and markets cannot do the "job" alone. The public sector still has a role to play in ensuring that a conducive environment exists for the development of sustainable agricultural mechanization in SSA. For example, the government needs to play a key role when developing agricultural mechanization strategies that will guide implementation of the planned actions. Furthermore, this will foster new and innovative models of public-private partnerships (PPPs) that include the numerous opportunities provided by the social and shared economy, (via information and communication technology (ICT) and social media platforms, for example), that could play a key role in the successful development of a regional framework for sustainable mechanization.

Integrate mechanization and good agronomic practices for environmental sustainability

In Africa, the Green Revolution has not had the same impact as it has in Asia. Mechanization and intensification levels, fertilizer use and the integration of other modern technologies have remained low throughout most of the continent today.

However, degraded lands are common across the continent and it is astonishing to see how soil erosion has progressed in many regions considering the low level of mechanization. There are many reasons for this. One is the continuous use of the plough (or hand hoe) that leads to soil degradation; the creation of plough, or hoe, pans in the soil profile; and loss of fertile top soil. Looking to the future, if Africa should intensify and mechanize its agriculture on a large scale, it must be done with care and in line with the principles of Sustainable Production Intensification (SPI) that FAO has summarized, in its "*Save and Grow"* guidelines [10, 11, 15].
Farming systems for SPI will offer a range of productivity, socio-economic and environmental benefits to producers, and to other value chain players and to society at large. These will include greater and more stable production, food distribution and profitability; adaptation and reduced vulnerability to climate change; enhanced ecosystem functioning and services; along with reductions in agricultural greenhouse gas (CHG) emissions and "carbon footprint'. In a nutshell, agricultural mechanization in the twenty-first century should be simultaneously: environmentally compatible, economically viable, affordable, adapted to local conditions and, in view of current developments in weather patterns, also "climate-smart'.

Special focus on increasing agricultural mechanization among smallholders

The topic of agricultural mechanization for smallholder farmers (in Africa) has, for a long time, been a neglected one. It is now clear that mechanization is an essential input to raise labour and land productivity and reduce drudgery. Mechanization can also be used to add value to primary products, and so, produce employment and income potential along the value chain [32].
Quantitative data on the specific impacts of mechanization as an essential production input on smallholder farming systems in Africa are by nature, site-specific and so generalizations are not always easy to make; but some authors have focused on the issue both in Africa and also particularly Asia. It was reported that in South Asia that disaggregating the production labour tasks per type of crop, type of farm and location of farm can provide a clearer picture of labor productivity per task and it was found that overall productivity tends to rise with mechanization [1].
There is also unanimous agreement among experts that it is particularly women, youth and the elderly (mostly women again) who are responsible for the major burden of hand labour inputs in SSA, and hence, have the highest demand for additional farm power, simply to reduce drudgery.
In Section 3, the major contributions that mechanization can make in Africa were reviewed and include: increasing labour productivity; expanding the area under cultivation; increasing land productivity (especially through improved timeliness of operations); improving profits; and reducing drudgery. Yet, mechanization initiatives today must be inclusive and be even more bold. If promoted by donors, international institutions or through PPPs they need to not only include smallholder farmers, but should also focus on supporting smallholder farmers in gaining access to sustainable mechanization services. The argument of reducing drudgery and hence making farming more attractive should be the overriding one, perhaps even as important as economic viability [15].

Enhancing the role of the private sector involvement especially in the context of support to smallholders

There are two levels of private sector involvement. At the macro level it is crucial that international technical development institutions (such as FAO) and national, regional or global players in agricultural machinery industries (such as the European Committee of Agricultural Machinery Manufacturers Associations– CEMA), should join forces with international finance institutions and donors (World Bank, International Fund for Agricultural Development – IFAD, African Development Bank – AFDB, European Union – EU, etc.), and with the national governments or the regional bodies (e.g. the African Union – AU) to facilitate transformation of African agriculture and its related agro-industry to be more business oriented on the one hand, but to reach out to the majority of farmers in the continent – especially to smallholders. It is a matter of fact that small-scale and family farmers are the largest private investors into African agriculture [6].

It is critical to promote such conducive and enabling environments which facilitate the adoption, sustainable use and development of mechanization. In this context, smart PPPs are needed to break the greater partnerships down to local implementation level.

Capacity building and entrepreneurship development for mechanization services providers (viewing the mechanization sector as a job creation opportunity – not a labour displacer)

At the local level, such initiatives need to put emphasis on capacity building schemes for enabling inspired young rural dwellers or farmers to become business entrepreneurs for sustainable mechanization services or for services related to it (repair, input supply, marketing, value addition). The development of competitive local, independent private sector entrepreneurs should be the key objective of such PPP initiatives. It would be a catalyst to creating new and more attractive jobs and employment (compared to the arduous and unattractive hand-labour based farming). Where appropriate, the support could be provided through promoting cooperatives or facilitating reforms for the enforcement of legislative and regulatory frameworks for making such efforts possible at the local government levels in the countries concerned. Decentralization of decision-making should be part of entrepreneurship development actions.

Addressing logistical challenges and those totally outside the control of humans

Service provision in agriculture and especially in field-based mechanization (anything before harvest) is a risky and seasonal business. Farmers shy away from investing in expensive inputs or even in services. On the other hand mechanization service providers need to take an extra risk to provide services to smallholders with their often remote, un-even, smaller fields. To compensate for this to some extent, service providers should seek to diversify into other businesses that are less seasonal, outside the agricultural sector (transport, rural roads maintenance), or in post-harvest processing, so that the long and risky growing season becomes less dominant in their planning (**Figure 13**).

Today, with the increasingly unpredictable cropping seasons and enhanced effects of climatic events, such as El Niño with its related drought spells, it is not possible to assume that yields and subsequent income will be forthcoming, as required to compensate for the time and money invested into services for land preparation, tillage, planting, weeding etc. It is the sometimes brutal reality of farmers' rural life in Africa that is increasing the risk.

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