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EDITORIAL

The idea of SDGs is becoming a trend in many fields now. World population is continuously and constantly increasing and expected to reach 9 billion in near future. The surface of our mothership Earth is limited. The space of forest and farmland is also limited and its expansion is getting to be difficult. For example, Brazil is trying to cut Amazon forest for development, but executing the plan will be difficult due to severe criticism from all over the world. In the case of Africa, there is a lot of undeveloped spaces and it could be used as additional farmland, but preserving forest is strongly demanded amid global warming. So they cannot freely cut the forest and turn it to be farmland.

Countries in Africa, especially Nigeria, are experiencing the most rapid speed of population increase in the world. In spite of a drawback of a decrease of farmland per capita, all the players in the agriculture fields have strived to produce enough amount of food per capita. In the long run, the most important technology is the one for improving land productivity. As I have said again and again, timely and precise work is the most essential factor to achieve high land productivity. It is realized by proper proliferation of agricultural machinery. No agricultural machinery, no timely and precise work. Agricultural machinery improves not only land productivity but also labor productivity.

The biggest challenge for agriculture in Japan is a steep decrease in the number of the agricultural workforce caused by farmers' aging. The number of employment in agriculture in Japan fell below 2 million and 80% of them are over 60 years old. Innovative agricultural mechanization is needed that will compensate for the rapid decrease of the workforce required.

Similar issues are about to descend onto other countries. The average age in rural districts in China is already over 62 years old. There are other countries which suffer aging caused by the emigration of young people from rural areas to urban areas. A new way for agricultural mechanization is to informatization of machinery, in other words, robotization. Development of agricultural robot in accordance with each area and each crop is getting to be necessary all over the world including the developing countries. We should try to realize the innovative mechanization together.

Yoshisuke Kishida
Chief Editor
October, 2018

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AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

Vol.49, No.4, Autumn 2018

Agricultural Mechanization in Morocco: Historical, Present Situation and Future Prospects

by
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Abstract

In Morocco, different forms of agricultural mechanization coexist, based on human energy, animal traction, moderately motorized and in rare cases we also find an intensive motorization based on the latest technologies (automation, precision farming ...). The agricultural tractor has been part of the rural landscape for more than four decades. The dynamism induced by the Green Morocco Plan, through the government incentives, is causing a transformation in the field of mechanization through new mechanized operations (particularly harvesting, crop protection, irrigation, indoor farm and product valorization). However, several deficiencies remain in the quality of use of tractors and agricultural equipment and their maintenance. The new agricultural advisory mechanisms recently put in place are responsible for meeting these challenges. Training and research systems exist and have a sound foundation and solid experience forged through collaboration with several foreign centers of excellence. But, it currently lacks resources, coordination, attractiveness for young people and the lack of an institutionalized relationship with professionals of machinery sector. The agricultural equipment import and distribution sector is very strong and well structured. On the other hand, the local manufacturing sector is still modest and suffers from fiscal, financial and competition constraints of the informal sector. For maintenance, apart from the professionals who have structured networks in the cities, it is the craftsmen and repairmen who take over in the villages. Given the current situation of agriculture and the institutional and economic environment, the prospects for the development of mechanization are promising.

Key words: mechanization, morocco, subsidies, import, local manufacturing

Introduction

The level of agricultural mechanization in Morocco remains below the needs of agriculture and several forms coexist, from manual labor to computer-controlled irrigation, through animal traction and conventional motorization. This varies according to the agro-ecological zone, the production system and the type of exploitation. Manual labor is used in weeding of row crops and crop harvesting except for grains. Animal traction is still omnipresent in hilly areas. This mechanization has strengths, but also faces many other constraints.

Government Policy for Agricultural Mechanization and Future Prospects

Evolution of Agricultural Mechanization

Since independence to date, the government has continued to encourage agricultural mechanization. It had set up the investment code in 1969, which established subsidies for agricultural tractors and accompanying equipment. Agricultural equipment has been exempted from customs and import taxes since 1982 to the present day. The analysis of the evolution of these state incentives is characterized by a constant in the promotion of agricultural mechanization, however it shows variations of the rates and the quality of the beneficiary of the subsidies, but it reveals changes in the types of equipment and categories of producers concerned. These variations are due to minor policy changes but especially to the impact of the successive droughts that have plagued the country. They are also guided by a concern for improvement and iterative optimization of these incentives.

In the absence of a recent national data, the authors have attempted to rebuild the national tractors fleet based on the general agricultural survey (RGA) 1996 and annual sales of equipment provided by Moroccan Association of Importers of Agricultural Equipment (AMIMA), data available from Exchange Office, their statistics and the studies carried out at IAV Hassan II. **Fig. 1** shows the reconstruction of the evolution of the agricultural tractors fleet used in the country during the period 1985 to 2016. The study of this evolution shows the marked periods, stagnation or even a slight decrease during the period 1993-2005 around an average of 45,000 tractors and then an average increase of the tractors fleet of 5.2% during the period 2005-2016 (6.3% during the period 2005-2009 and 3.6% during the period 2009-2016). These variations are due to droughts or years of good rains or the effect of State aid or the combination of several of these factors. The fleet of tractors in use is estimated in 2015 at 64,000 units, representing 72% of the theoretical needs based mainly on conventional agriculture.

During the period 1969-2005, subsidies for agricultural tractors fluctuated between 10 and 30%, with 20% for individual farmers and 25-30% for groups. The year 2006 marked the beginning of the improvement of the government incentives (40% of the tractor's price with a maximum of 9,600 US$). The advent of the Green Morocco Plan (PMV) in 2008, marked a real turning point, with a significant increase in subsidy rates (30 to 70%, or even 100% for small farmers associated in non governmental organisation (NGO) or grouped in cooperatives) and improve the conditions for granting this aid. The government encouraged the grouping of small farmers around aggregators who provide investment and agricultural supervision for the improvement of production and ensuring the collection, storage, marketing and/ or valorization of the agricultural product) and receive in return subsidies for committed investments. The procedures for awarding grants were successively reduced in 2007, 2008, 2010 and 2011. The eligible list was gradually extended to new machines.

Constant and Sustained Government Efforts for Mechanization

The current context of liberalization of the agricultural sector, imposed by the multiple agreements, represents an unprecedented challenge for the sector and the PMV shows that there is a real political will to take up this challenge. In this way, agricultural mechanization that goes beyond simply increasing the power of labor (labor-capital substitution) through mechanization that allows better control of labor intensity and improves productivity and competitiveness is crucial for the future achievement of this goal (Ministry of Agriculture and Maritime Fisheries (MAPM)-Food and Agriculture Organization of the United Nations (FAO), 2011).

Beside the difficulties arising from climate hazards, farmers currently have favorable conditions through government aid for purchasing agricultural machinery and equipment. For example, government subsidy rates range from 30% to 70%, or even 100% for groups of small farmers with projects. Procedures are streamlined and standardized in one-stop-shops for processing applications that are created in every province. Agricultural equipment and machinery are exempt from Value Added Tax (VAT) when they are intended for agricultural use exclusively (Ministry of Economy and Finance, 2017). In addition, land tenure status no longer seems to be a constraint for investment, public-private partnership (PPP) is encouraged (MAPM-FAO, 2011) and access to credit (historically through "Crédit Agricole", currently other conventional banks get into it) is facilitated. With regard to climatic hazards, as part of a PPP, government-subsidized risk prevention and mitigation instruments (multi-risk insurance for arable crops and arboriculture, anti-hail program, insemination of clouds in case of drought, ...) were put in place.

The World Bank ranks Morocco at the 17th place in the business of agricultural machinery on a sample of 62 countries where the time and cost of homologation, testing, maintenance, registration and import

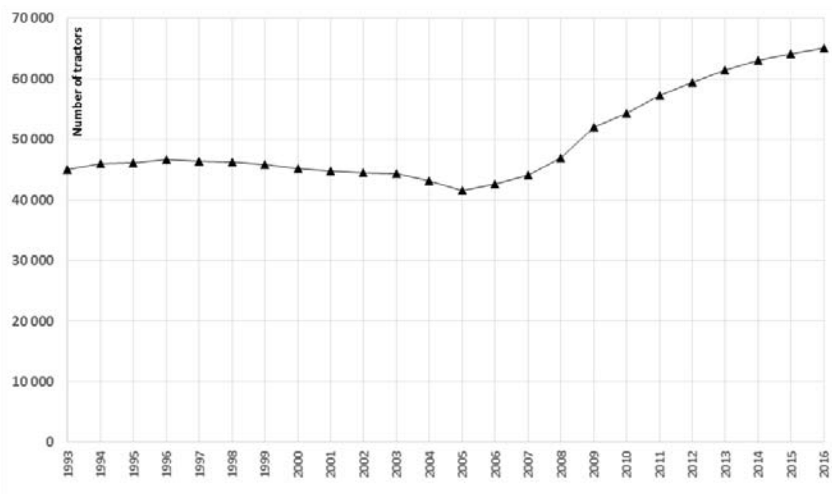

Fig. 1 Evolution of tractors fleet in use (new and used) in Morocco during the period 1993-2016 (elaborated from the MAPM, AMIMA data and our calculation)

procedures are considered (World Bank, 2017).

The various field studies show that despite the low level of mechanization (0.56 kW/ha) and the shortages of machinery at the time of crop establishment and the harvest of several crops, agricultural tractors are still underutilized (400 to 600h/year), except for a few large modern farms, often irrigated, in particular orchards (1,200 h/year or 20 ha per fruit tractor). In addition, the maintenance standards of the equipment are often not well respected and the management of the work is not optimized. Long-term work by both farmers and operators is needed to upgrade these aspects. In fact, a large part of agricultural operations, especially for the 6 million hectares of arable rainfed crops, is provided by mechanization service providers who have not received any training in the field (**Fig. 2**).

The evolution of mechanization in the short, medium and long term, should follow the pace of the PMV, follow its guidelines and support its objectives in terms of areas planted or production to be harvested and packaged and/or stored at the farm or the community level. The agricultural equipment fleet will continue to increase slightly. In contrast, the greatest progress will be expected in a further intensification of the use of tractors with the objective of 800 h/year in rainfed agriculture and 1,200 h/year in irrigated, through the diversification of activities with more tractor tools and more rental service and/or use in common (**Fig. 3**). This involves a specific agricultural extension program and a thorough work.

Finally, there is a great potential for investment in precision farming weather for producers or service dealers. The constraints imposed by various partnership agreements in terms of agricultural product quality and environmental protection push toward the adoption of rigorous itineraries often requiring precision agriculture. This necessity is also dictated by the pressure imposed by climate change and by costs competitiveness,. Several foreign companies anticipate these future needs and stared already their introduction on the market (Bourarach, 2010).

Fig. 2 Common equipment for soil tillage and fertilizer application for cereals (photo: Bourarach)

Importation, Marketing and Local Manufacture of Agricultural Machinery

Historical

The import, local manufacturing and marketing sector is based on fairly well organized and structured economic actors throughout the national territory, relayed at the local level by an informal sector consisting of relatively dynamic craftsmen and repair mechanics offering fairly adequate local service.

The review of the evolution of sales of new tractors, from data period 1993-2016 (MAPM data, AMIMA, Registration Service and the Exchange Office), shows three phases:

- Period before 2004: Annual sales were low and ranged between 777 and 2,311 agricultural tractors. During 1993-2004, average annual sales recorded are 1,294 units. The variations recorded are explained on one hand by the recurring droughts of the nineties and the consequent development of used imported equipment that occurred during the period 1993-2000 (MAPM-FAO, 2011).
- Period 2004-2009: Sales of tractors climbed from 1,150 in 2005 to 6,791 units in 2009, due to the improvement of the mechanization support system (2004: increase of tractor subsidy to 40% with a ceiling at 10,000US$, establishment of the one-stop-shops for processing aid application in 2008), prosperous agricultural years and the dynamic created by the advent of the Green Morocco Plan in 2008.
- Post-2010 period: Sales fall to around 4,000 tractors a year and then fall around 3,000 units (2015). This drop is explained more by an uncertain climatic variability than by poor agricultural campaigns. However, government aid and the stimulating effect of the PMV have certainly been important in maintaining sales at a level that is relatively average, but low to support current agricultural development and especially to cope with the bottleneck installation of fall crops (AMIMA-IAV Hassan II, 2015).

The evaluation of the factors contributing to agricultural performance shows that there is a strong correlation between sales of new farm machinery (particularly trac-

Fig. 3 Forage rake tedder and baller (Photo: Bourarach)

tors) and cereal production, especially in rainfed areas (**Fig. 4**). Overall, the "best" agricultural years correspond to the "best" sales of agricultural equipment, especially when this coincides with other incentives linked to the conditions for granting the subsidy (2006, 2009) and the promotion of mechanization (such as for example the International Exhibition of Agriculture in Morocco (SIAM), where professionals make about 30% of their annual revenue). In order to adjust to climatic hazards, the adoption of conservation agriculture and the choice of equipment and related techniques are crucial for the sustainability of the agricultural sector. Moreover, the fleet of tractor accompanying equipment is estimated at about 157,000 units in 2010, or about 2.5 tools per tractor.

Current Situation

The import and distribution of agricultural equipment is provided mainly by a ten companies (ALL STOCK, COGEPRA, COMICOM, DIMATEQ, ETS.K. SLAOUI, FORAGES ET TUBAGES, SOCOPIM, SOMMA, STOKVIS MOTORS, STOKVIS NORD-AFRIQUE) which are relatively well structured and represented on the national territory through local agencies. These are organized in association defending their interests: Moroccan Association of Importers of Agricultural Equipment (AMIMA). These companies control more than 80% of the national market and have networks of retailers covering the entire national territory. Thus, they directly employ about 1,500 people and indirectly 6,000 to 7,000 people. They have an annual turnover of more than 270 million US$ of which 85% is represented by agricultural tractors (MAPM-FAO, 2011).

The imported tractors range from 30 to 160 HP and come from Europe, North America, Japan, India and China (the 40-100CV range accounted for 88.1% of sales in 1997). These companies also market other equipment such tillage tools, seeding and planting machinery, grains and fruit processing, grain and tubers harvesters, livestock equipment, handling, transportation and storage equipment.

From importers-distributors of agricultural equipment point of view, the constraints to the development of their activities and thus to the development of the country's agricultural mechanization are related to the exorbitant taxes imposed on spare parts and the problems of financing of equipment to farmers (MAPM-FAO, 2011). The farmers fold on adaptable parts often of poor quality, but cheaper because not necessarily paying the 20% of VAT. However, competition at both international and national levels means that equipment prices are compressed to a minimum and spare parts are the ones the profession would make a profit from. The turnover of the original spare parts is about 22 million US$, or 8% of the total turnover, while the adaptable spare parts represent the 3/4 of the market, that is 13 million US$ loss of VAT revenue for the government (MAPM-FAO, 2011).

The agricultural machinery industry in Morocco, despite the small size of its domestic market, is relatively dynamic and upgrades its production tools, in recent years. The agricultural equipment manufacturing sector consists of a formal sector and a parallel informal sector. The formal sector has about twenty companies and/or manufacturing units, dominated by three companies: ATMAR, COMICOM and ETS. HASSOUNI. The formal sector produces tillage tools, agricultural and water transportation equipment, sprayers, pumps, stationary threshers, grain and tuber cleaners, feed preparation machines, simple livestock equipment, and spare parts. The formal sector, rely on the momentum provided by government incentives. They have invested in new production tools (numerically controlled machine tools, plasma cutting, oven-drier electrostatic powder paint, etc.). These are dynamic small and medium-sized private companies, with some looking to improve their products and introduce new ones, even if they do not have real quality services and no development de-

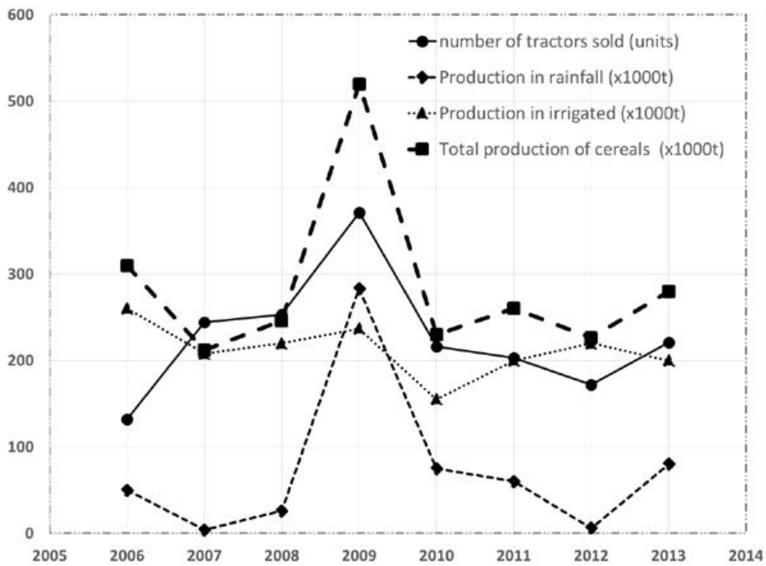

Fig. 4 Evolution of sales of agricultural tractors and cereal production (irrigated, dry and total) in Tadla Azilal region (2006-2013) (Source: Impact of subsidies on mechanization development, AMIMA / IAV Hassan II (2015))

partments. In Morocco, 75 to 100% of tillage tools are locally produced, 10% of fertilizer spreaders and sprayers are locally produced. 90 to 100% of trailers and water tanks are also manufactured locally. During drought years, these companies produce more water tanks and civil engineering equipment, thus ensuring their sustainability.

The material manufactured is relatively good quality. Farmers emphasize the availability and affordability of locally manufactured farm equipment spare parts. These units need a human resource upgrade, manufacturing techniques and the establishment of a quality control department.

The agricultural machinery manufacturing units of the informal sector are found in most large agricultural regions. In fact, they are repair shops and craftsmen who repair tractors and agricultural machinery throughout the growing season and secondarily manufacture agricultural equipment on specific requests. Some mechanical manufacturing workshops are specialized in providing service to these artisans. This device spontaneously formed on the basis of real needs of the field, constitutes an opportunity of creation of network for manufacturing "cluster". The machines and tools made are mainly tillage tools and post-harvest machines. Professionals estimate the contribution of the informal sector to be about twice that of the formal sector.

Fig. 5 Sugar beet mechanization in Moulouya area (Photo: Bourarach)

Moroccan industry suffers in general from the high cost of "energy". Awareness of this fact and the growing domestic needs, Morocco invests in the production of electricity from renewable sources; wind and solar energy. A large-scale program has gradually being launched (National Programs for Renewable Energy Development and Energy Efficiency (PNDEREE), 2010-2020 in Morocco) which will increase the share of renewable energies in the national electricity mix to 42% by 2020 and 52% by 2030. At the end of 2016, the rate of rural electrification reached 99.43% (connection to networks: 39,445 villages or more than 2 million households, equipped by individual photovoltaic kits: 70,659 households in 4,555 villages). The total population who benefited from electrification under the Global Rural Electrification Program (PERG) is estimated at 12.7 million inhabitants (National Office of Electricity and Drinking Water (ONEE), 2016).

Future Prospects

The theoretical needs for 2020 under conventional tillage system, are estimated at 98,500 tractors, 264,000 farming tools, 17,100 combine harvesters, more than 22,600 portable olive vibrators and around 3,500 olive harvesters, in addition to other tools and small equipment for orchards, animal productions and post-harvest, both motorized and animal-drawn (MAPM-FAO, 2011). It is estimated that the annual average requirements by 2020 would be 3,000 new tractors (4,000 units in good agricultural years, 2,000 units in years with low rainfall). The average annual requirements for accompanying equipment would be 12,000 units based on a ratio of 4 tools/tractor. Agricultural machinery professionals have the financial and human resources to meet these needs. The mechanization of harvesting of fruits, especially olives becomes crucial, for reasons of lack and high cost of hand-labor, requirements and standards of delivering agro-industry and the International market requirements and reducing losses (**Fig. 5**). Equipment needs for the olive harvest in 2020 would be more than 22,000 portable vibrators, 8,000 towed vibrators, and about 3,500 propelled harvesters (Bourarach *et al*., 2012).

According to a study carried out among farmers by IAV Hassan II* for AMIMA, the subsidy with its rates and conditions of granting allows the autonomy of the farm compared to a labor force is more expensive. Moreover, the quality of work that affects product end use and productivity; and to a lesser extent the opportunity for smaller farmers to provide mechanization services are the main determinants for the acquisition of agricultural machinery (AMIMA, 2015). At present, the rates and conditions for granting government financial aid have never been more favorable to agricultural mechanization. As for autonomy and the quest for the independence of a labor that is increasingly rare and expensive, it only needs to be exacerbated over time. On the other hand, the quality of products is increasingly dictated by the development of agribusiness and an increasingly global market requirement.

From above mentioned determinants, which will only be reinforced and in view of the needs generated by the PMV and taking into account the public and private investments foreseen, the market for agricultural machinery and equipment has good prospects in the future and it is expected that these orientations will go beyond the 2020 horizon.

Present Status and Future Prospects Of Agricultural Machinery Training and Research

Research and development programs are mainly conducted by public institutions (academic training or research institutions (IAV Hassan II; INRA and National School of Agriculture of Meknes) and sometimes international development agencies)**. However, in most of developing countries and Morocco as well, the purpose of most of the academic research is for graduation either Msc or PhD and there is less follow up on the subject after graduation. Even if the subject is linked to real farmers and the market's need, the transition to manufacturing and commercialization is difficult. Research programs are dealing with conservation agriculture (development of machinery), energy balance and efficiency, renewable energy, harvest and post-harvest.

All the research and development programs funded by private sector are market and marketing oriented even when these are contracted to public institutions. The Research Team believes that imported products and technologies can satisfy all the needs of farmers and different farming systems. The Team also claims that all the efforts to be oriented toward marketing and training of users on available international technologies. From the discussion above there is a clear discordance between public and private strategies and there is a lack of coordination between the two visions. There is neither a structure nor any coordination between the stakeholders on the ground.

The Moroccan government is offering integrated curricula of programs and training for different levels from qualified labors and technicians to doctorates. The qualification is intended to students with at least primary education level and experienced farmers. The technicians are either high school graduated and two years for specialized technicians in different areas of mechanization and engineering or high school level and two years training for general mechanization programs. Engineers are graduating from IAV Hassan II after five years of higher studies. This system lacks human and material resources and coordination, attractiveness for young people and needs more institutionalized relationship with professionals. However, from the national mechanization strategy the identified needs by 2020 are 110,000 qualified service providers, 53,000 mechanics, 27,000 technicians and more than 450 engineers. However, this should not make us forget that sustained competitiveness requires the implementation, in parallel, of programs and actions that are sustainable: a research and teaching system with human and material resources to support farmers and machinery professionals over time and enable them to compete on the international market (MAPM-FAO, 2011).

Conclusions

This overview of agricultural mechanization in Morocco reveals a great contrast between different agro-ecological regions, different types of farming systems and different commodities. Thus, several levels of mechanization come together: (i) hand tools, (ii) animal traction and (iii) agricultural motorization, using portable power tools, tractors tools and using self-propelled machinery. In contrast to irrigated areas, rainfed agriculture is vulnerable to climatic hazards. The PMV has brought more opportunities in the overall vision of the agricultural sector and has set achievable targets and implemented financial supports from the government to deal with socio-economic constraints and the low level of mechanization and mitigate the effects of climatic hazards. A major effort is to be implemented by National Office for Agricultural Advisory Services (ONCA), recently created to promote through the public and private agricultural advisory services for the development of a specific program for agricultural mechanization in order to optimize the farm equipment fleet and rational use of it. Machinery professionals have the means to meet the needs generated by the modernization of the Moroccan agriculture. The quantitative and qualitative ongoing improvements of agricultural mechanization would inevitably be accompanied by its adaptation to climate change by enhancing green technologies (conservation agriculture and renewable energy use in the production, storage and recycling of products and agricultural by-products…).

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* Research team (Dpt Energy and Agroequipment): Baali E. H., Bourarach E.H. (coordinator), El Himdy B. and Houmy K.

**Research in agricultural machinery is conducted in the country by a dozen researchers (or teachers and researchers) spread over three institutions: IAV Hassan II (Department of Energy and Agro-equipment, 9 teacher-researchers); INRA, 3 researchers), and ENA-Meknes (Department of Agricultural Machinery, 2 teacher-researchers).

Current Status of Agricultural Mechanization in East Africa

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Abstract

In East African countries, such as Uganda, Kenya, Tanzania, and Ethiopia, agricultural mechanization is not a recent phenomenon. However, the penetration rate of agricultural machinery, such as tractors, still does not exceed 30%. Under such circumstances, mechanization is advancing in the form of service activities, such as rent plowing and rent harvesting. In particular, power tillers are effective for the small-sized fields owing to the fragmentation of land and small holdings per farmer; further, the introduction of combine harvester is effective in expanding rice cultivation in East Africa. Although the penetration rate of agricultural machinery is low at present, it is expected to promote the different status of mechanization in each country.

Introduction

During the period from 2013 to 2016, the author conducted a survey on agricultural mechanization in East Africa through a "Feasibility Survey Project on Agricultural Mechanization for the Small Scale Farmers in Sub Sahara Africa." This was implemented under a subsidy from the Ministry of Agriculture, Forestry and Fisheries (MAFF) of Japan. The target countries were Uganda, Kenya, Tanzania, and Ethiopia. In this document, the agricultural mechanization policy of each country will be introduced, as well as the actual status of agricultural mechanization. In particular, the mechanization related to rice cultivation will be discussed first. After that, the desirable mechanization in these areas will be considered.

Overview of Countries in East Africa

In East Africa, Uganda, Kenya, and Tanzania are arranged together in a clockwise direction, starting from Lake Victoria in the north; Ethiopia is to the north of Kenya. The area of Uganda, Kenya, Tanzania, and Ethiopia is 241,000 km^2, 580,400 km^2, 945,100 km^2, and 1,104,000 km^2, respectively.

The equator passes through the southern part of Uganda, but its average altitude is 1,100 m; thus, it has mild climatic conditions throughout the year. The annual average precipitation is 1,200 mm, and it has adequate water resources; thus, it is one of the African countries that is well-suited for agricultural production. Agriculture is a major component of its economic base; it accounts for 42% of GDP, 85% of the exports, and over 80% of the population works in agriculture or its related fields. The GDP per capita is USD 604 (2017).

The major industry in Kenya is agriculture and it accounts for 30% of GDP and 65% of the total exports. In terms of labor force, about 70% is believed to be engaged in agriculture. In addition, industrialization is more advanced than in other East African countries, and the development of the manufacturing industry is remarkable. The GDP per capita is USD 1,507 (2017). In the northern part of Kenya, the desert area dominates and the eastern part becomes semi-arid toward the coast. However, in the central and the western parts, the precipitation is relatively high thus, these are suitable for agriculture.

In Tanzania, agriculture also accounts for about 30% of the GDP. It is a major industry that accounts for about 70% of the workforce, but most are said to be traditional small-scale farmers practicing self-sufficient agriculture. GDP per capita is USD 936 (2017). Most of Kenya's land receives rain in the summer, while in the winter, it has a less rainy savanna-type of climate. The central part has a dry steppe climate, and the coastal part has a tropical climate with high temperature and humidity.

In Ethiopia, agriculture accounts for about 40% of the GDP, and it is a major industry that accounts for about 85% of the total employment. The GDP per capita is USD 767 (2017). The climate changes according to altitude and it can be classified into: a cool highland type of climate at an altitude of 2,400 m or more; a temperate plateau climate at an altitude of 1,500-2,400 m; and a high-temperature lowland climate at an altitude of 1,500 m or less. The average annual rainfall exceeds 2,000 mm in the southwestern part, while it is less than 100 mm in the lowland in the northwest. Generally, the precipitation in the western region is large and decreases as one goes toward the east.

Agricultural Mechanization Policy

In Uganda, the government-led tractor extension project was on track in the 1960s and 1970s, but in the 1980s tractors were sold off to the private sector owing to the onset of privatization. However, the machinery did not remain in Uganda; Kenya's private sector bought those tractors. In terms of the agricultural mechanization in Uganda in recent years, it is estimated that about 90% of farmers do not have access to agricultural machinery. For the remaining 10% of the farmers, access to agricultural equipment is limited mainly to that used for livestock farming during plowing work, and the use of tractors is limited. Under these circumstances, expectations for agricultural mechanization are increasing, and in 2012, a detailed implementation plan for the agriculture sector called the Development Strategy and Investment Plan (DSIP) agricultural mechanization subprogram and the Framework Implementation Plan (FIP) of the Agricultural Mechanization Taskforce were created. Among these, the FIP clearly indicated that it will support farmers and private companies utilizing agricultural machinery. First, given that medium- or large-scale farmers with financial resources are introducing machines and enjoying the merits of mechanization, it is hoped that the effect will spread to small-scale farmers. FIP has four key components. Thus, it is a policy and institutional framework for promoting mechanization, besides being support for acquisition and utilization of agricultural machinery, improvement of post-harvest processing technology for specific crops, and improvement of machine related information.

The current mechanization rate in Kenya is low; 50% of the farming is done by human power; 20% by livestock power; and 30% by the motive power of machinery. The government is promoting the expansion of agricultural policies utilizing modern technology, and it is focusing on not only the land that is currently cultivated, but also the 2.5 million acres of unused land. In addition, the government is focusing on the mechanization of small- and medium-scale farmers in particular. It is are seeking to expand productivity by converting self-sufficient farmers to modern and commercial-oriented farmers and mechanizing them. In addition, they have partnered with the Brazilian government to allow farmers to purchase mechanized equipment at reasonable prices, and through the grant-in-aid from Japan, they are supplying agricultural machinery worth JPY 460 million to the rice farmers.

In Tanzania's survey in 2013, the mechanization percentage for plowing was 62% by human power; 24% by animal power, and 14% by machinery, such as tractors. Farmers utilize tractors mainly in Morogoro, Arusha, and Kilimanjaro regions. It is said that farmers in Mbeya farmers make extensive use of power tillers. The utilization of tractors is less by private owners and unions, and most of them are used on a custom hiring basis. According to the Tanzania Agricultural Mechanization Strategy (TAMS) (2006), the agricultural mechanization challenges include the limited ownership of agricultural machinery, absence of funds to purchase machinery, undeveloped agricultural finance system, lack of operators and mechanics, lack of mechanization packages suitable for major agricultural work, vulnerable private sector, and lack of expertise.

The agricultural mechanization policy in Ethiopia is the Ethiopian National Agricultural Mechanization Strategy formulated by the Ministry of Agriculture and Agricultural Transformation Agency (ATA). Among other things, it states that animal power accounts for about 87% of the mechanization and the remaining 13% is by tractor. The numerical target for mechanization by 2025, based on input energy per unit area, is set at about 2.5 times the present value. The division of roles of each sector has been established for supporting the mechanization of small farmers. In addition, ATA distributes power tillers and threshing machines to farmers and conducts field surveys. The Agency is also conducting cutting tests on teff with a large combine harvester.

Actual Condition of Agricultural Mechanization

In Uganda, the large-scale operation of tractors is mainly in the sugar industry, which is managed as plantation agriculture, and in tobacco cultivation, oil crops and others. These business establishments have training and maintenance facilities, and have established a system that can basically manage itself. On the other hand, for small- and medium-sized farmers, the use of small machinery, such as the power tiller, is only possible with government support. For example, a farmer who introduced a power tiller can cultivate horticultural crops in the suburbs of the capital city and bring it to the market in urban areas for sale. In some cases, the cultivation area can be expanded to about 5 times the current size by introducing mechanization. Regarding the use of power tiller, technical guidance is necessary from selection of attachment to maintenance.

In addition, the custom hiring of tractors and power tillers is also being carried out. Hiring cultivation services in Uganda have been privatized since the 1980s. The National Enterprise Corporation (NEC) was among the private companies established by the country's initiative in the commercial sector of Uganda's military department. In addition to conducting agricultural machinery sales business, NEC was providing plowing service at USH 100,000/acre and harvesting service at UGX 70,000/acre. The challenge faced is the scarcity of cash among the farmers, who are its main customers, and there is a possibility that the payment for the work done will be delayed. Further, there are farmers who request for services without first removing stones and stumps in the field, leading to machine breakdown. Northern Uganda Agricultural Center (NUAC), which is financed by Denmark, is another example of a private company; it has a hiring service, besides a production section with agricultural land of 800 hectares, sales and repair section of agricultural machineries, and an agricultural processing section. Its tractors are mainly those with 90-130 horsepower.

Further, some individuals do custom hiring service for cultivation, but it is difficult to estimate the scale. For example, a sole proprietor in Kampala, the capital, repaired a broken tractor and began a hiring service. The project was kept going with own funds and an interest-free loan from a friend, and the plowing charge was UGX 130,000/acre (about JPY 3,800). The problem was that the efficiency did not rise or there was breakdown of machinery on agricultural lands with stumps, etcetera. Sometimes they used transfer by mobile phone to collect payment for the hiring service performed.

Regarding two-wheel power tillers, a demonstration of the power tiller was conducted by the author in the survey activities in northern Uganda and, as a result, once gathered more than 100 participants; thus, the demand for power tiller was understood to be great (**Fig. 1**). In Uganda, power tillers are used by some individual farmers. For example, farmers in the suburbs of Kampala were able to use power tillers with the support of National Agricultural Advisory Service (NAADS) in 2013; the farmers expanded the area under cultivation area from 2 to 5 acres, bringing vegetables to the Kampala market and increasing their income. One of the advantages of the power tiller is that it is possible to transmit power to other machines. In rural areas, where multiple power tillers were introduced with the support of Belgian NGOs, farmers connected the power from power tiller to the corn thresher and improved income. Further, after the demonstration in northern Uganda, introduction of power tillers began in the north; custom hiring services for plowing and seeding work have begun for not only major crops such as maize and upland rice, but also oil crops.

In the post-harvest sector, the effectiveness of removing stones from rice by using a de-stoner was also studied on a feasibility survey conducted by Japan International Cooperation Agency (JICA).

The de-stoner was made to be user friendly, especially for women users. It was: (1) small enough to be carried by a few persons and (2) knowledge about its operation and maintenance could be acquired after a few hours of workshop training. A year of monitoring showed that the value addition by removing small and, sometimes, white stones from the white rice gave rise to monetary advantages and profits. The value added "stone-free rice" not only affected the selling price and sales volume of the rice positively, but became a unique selling proposition.

The de-stoners that exist in Ugandan market are mostly made in China. Agriculture shops in urban area sell 2-3 annually. Their capacity of over 2,000 kg/h was found to be much beyond the requirement. Their price was close to, or above, the price of milling machines sold on the market. Many Ugandan farmers

Fig. 1 Demonstration of power tiller in Uganda

in rural area are not familiar with machines at all. Many machines, such as tractors and the Chinese de-stoner that were seen were out-of-service owing to faulty use, handling, or maintenance. This could be said about the overall agricultural mechanization in the rural areas of Uganda. Mechanization in the post-harvest sector is mainly confined to milling machines; other types of mechanization are overlooked owing to risks of breakdown and the small capital available to farmers. Labor is relied on to remove foreign objects from the harvested crops; most of the labor are women.

Rice sold to consumers, except that by the foreign companies or a few big local ones, is not mechanically de-stoned. Many small shops and retail stores de-stone with homemade sieves or by manual picking. One of the restaurants told that their staff to hand pick after purchasing the so-called "stone-less rice" as stones still make their way to the customer's plate. Completely eliminating small and white stone from rice by hand-picking is almost impossible. Further, hand-picking itself takes too long time as it relies on the visual inspection of every grain. The tests conducted on these retail rice varieties by using a de-stoner showed that most of the stones (1-10 stones/kg of rice) were small, white, or transparent and were very hard to distinguish visually from white rice. Furthermore, this test showed that a de-stoner can de-stone 5 kg/min, which was five times faster than the volume de-stoned by an experienced hand-picking labor at the retail store. During monitoring, it was found that a de-stoner can also de-stone other crops, such as corn, maize, beans, and peas. The de-stoner was used successfully not only for rice, but also added value to other crops. In addition, they let customers use it for a nominal charge when they are not processing their merchandise. This high processing speed provided women labor more time to rest and concentrate on other household chores and child care.

Fig. 2 Hiring service group moving with the rainy season

In Tanzania, only about 100,000 km^2 of the 440,000 km^2 land that is arable is used. Most agricultural work is manual even in the tillage work, which uses relatively more agricultural machinery, mechanization is only about 20%. The delay in mechanization is one of the reasons for the delay in the expansion of the arable land. More than 70% of the tractors were introduced by either direct purchase or aid in the 1980s, when Tanzania was a planned economy. Many tractors have been in operation for more than 20 years, and frequent breakdowns is a challenge. The supply of spare parts is another challenge, and about 6,000 tractors are lying idle despite being repairable.

In Tanzania, the custom hiring service has begun to spread. In particular, medium- and large-sized tractors make up a group of about 10 tractors (**Fig. 2**), and they travel throughout Tanzania. These can be hired for plowing service according to the rainy season in different parts. Further, tractors are commonly used for field preparations in the Lower Moshi region, where irrigated rice cultivation is thriving. Rotavator is commonly used for paddling. Service charge was TZS 35,000/acre (about JPY 1,700) for plowing and TZS 60,000/acre (about JPY 3,000) for paddling. In addition, the introduction of combine harvester was started in the Lower Moshi irrigated rice cultivation areas. At the time of the survey, the service charge was TZS 120,000/acre (about JPY 6,000 yen). As a result of the introduction of the combine harvester, the speed of work speed has increased and it is now possible to complete harvesting within the harvest period.

There is a spread of not only tractors, but also power tillers. The Tanzanian government purchased about 200 power tillers in the early 2000s and promoted the spread of machinery as an alternative to tractors. As part of the modernization of agriculture under the Kilimo Kwanza (agriculture first) policy, which started in 2009, a project to distribute about 50 power tillers to each prefecture was being implemented. The power tiller has high versatility and can be used to transport agricultural products.

Low-priced power tillers are sweeping the market, but there are many breakdowns and their evaluation by farmers is not very satisfactory. In contrast, the popularity of Japanese-brand power tillers is high, and they trade at high prices even if they are second-hand. However, obtaining spare parts, such as rotavator blades, remains difficult. In Kilimanjaro's Moshi area, power tillers were introduced as 2KR (Second Kennedy Round, Grant Assistance for Underprivileged Farmers), but many have already failed owing to use beyond their lifetime, or unavailability of parts. Recently, in collaboration with a local corporation, the sale of Kubota-made power tiller has started, and the supply system of spare parts is being improved.

It is said that more than 1,000 power tillers have spread in Mbeya in Tanzania. Among them, the Thailand-made Kubota power tiller has high durability, and has a waiting period. This power tiller is not a rotavator type, but a traction type developed in Thailand. Because it is simple structure and few failures, it is suitable for areas where spare parts distribution is lacking.

According to an agent in Mbarali District in Mbeya, they have been handling Kubota power tillers from Thailand since 2013, and had sold 300 units in 2015.

In Kenya, the Ministry of Agriculture, Livestock and Fisheries (MoALF) has 23 Agricultural Machinery Service (AMS) stations as part of its national agricultural machinery services network, which has spread nationwide. Each station owns an engineering machine and a tractor, and conducts public hiring service to earn revenue. The service fee is suppressed to be lower than the unit price of the market, which is said to be KES 1,500-2,000/acre. However, owing to the independent administration by each county, it seems that problems have occurred in the scope of service provision and implementation.

The challenges of mechanization in Kenya include poor machinery penetration service, inadequate access to mechanized technology, shortage of financial services available to farmers, and high price of agricultural machinery. Policies that provide incentives to each sector are necessary to solve the problem.

Further, in terms of mechanization of Kenya, J. Mutua *et al.* (2015) found that the segmentation of cultivated land becomes serious owing to fragmentation of land holdings. From the economic point of view, smaller agricultural machinery, such as the 2-wheel tractor, power tiller, have been found to be more useful than the 4-wheel drive tractor. In addition, power tiller can equip working machines and trailers, and the occupancy rate of machinery can be raised by performing work, such as sowing, threshing, and transportation, leading to effective expansion of agricultural production.

A major rice-farming area in Kenya is the Mwea irrigation scheme. In this scheme, plowing and puddling with tractor and harvesting by combine harvester have been widespread. The tilling work can usually be carried out by using a large tractor with rotavator. As for puddling, there are cases in which two or four-head animal power, drawing tooth harrow and levelers, is used. Although Chinese-made combine harvester have been introduced, the Japanese ones are highly valued. The local farmers' organization provided services for tractors and combine harvesters, besides preparing a maintenance schedule (**Fig. 3**).

In Ethiopia, it is said that there were 12,500 tractors in 2014, but the mechanization can be gauged from the fact that oxen account for 90% of the plowing (**Fig. 4**). The Fogera district of Amhara region, where the survey was conducted, bought 60 tractors (made in China) to promote mechanization. Rice cultivation is popular in the Fogera, but the rice-growing areas lack mechanization in plowing and harvesting. As in the case of threshing of wheat and teff, rice is spread on mortar-coated floor and several oxen step on it. There is a high possibility that it gets contaminated with stones and soil.

Regarding post-harvest processing, small rice mills are spreading in rural areas where rice is gathered. De-stoner and graders are not popular. Although the rate of broken rice is as high as 50% of whole rice, farmers use flour mills for rice. This is because there is a custom of using cereal powder, including rice, as a raw material in a cuisine based mainly on eating injera; so, the occurrence of broken rice during milling is not regarded as too much of a problem.

Discussion

Regarding what kind of machinery is demanded in each country, it is desirable that large- and medium-sized tractors are owned by individual farmers, who do not cultivate just their own fields, as well as business-minded entrepreneurs providing custom hiring service. This has already begun spreading in various countries; for example, in Tanzania, hiring groups that move according to the rainy season in an area are growing.

In contrast, it is thought that utilization of power tiller is effective for farmers having a small field. It can deal with fragmentation of land, which is emerging as a future challenge in Kenya, among other countries. Further, the advantage of power tiller is that farmers can increase the machinery occupancy rate by utilizing the power for various purposes. As in the case in Uganda, it is possible to raise the occupancy rate by using it in a corn thresher or sowing machine, thereby improving the profit of the power tiller. Especially, connecting a trailer to the power tiller and utilizing it for transportation is effective in raising the occupancy rate. In Mbeya, a group of power tiller users (using power tillers mostly made by Kubota in Thailand) are waiting for transportation work even during the off season, and it is known that they are moving for transportation in the

Fig. 3 Combine harvesters in warehouse of the local farmer's organization


Fig. 4 Oxen plowing in Ethiopia

irrigation area in the form of a mesh network (**Fig. 5**). Incidentally, the power tiller can be divided into the rotavator type and the traction type used in Southeast Asia (**Fig. 6**); the latter is considered to be more suitable. As for traction type, the handle is long and has the ability to deal with a number of attachments. Although the rotavator type is relatively expensive and it is difficult to create a distribution system to supply spare parts, such as blades, the traction type is simple in structure and relatively inexpensive; further, the plows can be developed and improved by development technology in East Africa. In Uganda, the Agricultural Engineering and Appropriate Technology Research Center (AEATREC) has developed a plow suitable for the local soil and sold it to users.

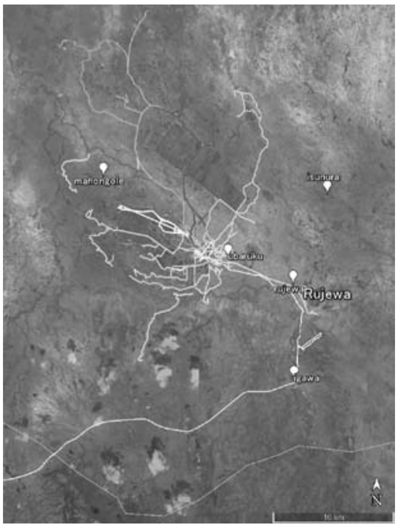

Fig. 5 Transportation route of 7 days and 9 user of power tiller in the dry season, Mbeya. Route data was collected by GPS

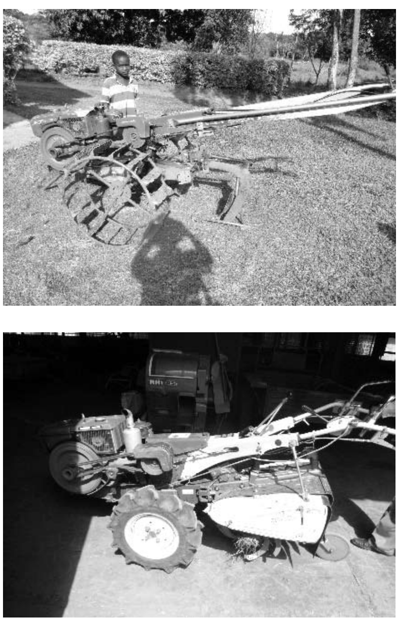

Fig. 6 Power tiller of traction type (upper photo) and rotavator type (lower photo)

In the various rice cultivation areas of East Africa, it can be inferred that it is desirable to introduce not only large tractors equipped with rotavator but also combine harvesters. The advantage is to eliminate labor shortage in harvesting, secure service fee collection, and control harvest loss. First, it is necessary to harvest rice in a timely manner, but the problem is that it cannot harvest at the desired time owing to labor shortage. With the introduction of combine harvester, quick harvesting becomes possible; the other advantage that the optimal harvest period is not missed. Next, in the case of hiring service, there is a problem that farmers cannot immediately provide cash; however, because the combine harvester leads to farmers getting income immediately after harvesting, the probability of service charge collection is high. In the case of manual harvesting and threshing, the harvest losses are large, but using the combine harvester makes it possible to minimize it.

Meanwhile, some machinery is not suitable for introduction at the present time. For example, during the demonstration in Uganda, the reaper was rated highly by participants, but since the reaper has a lot of small parts and it is highly likely that it would break down, using it without the supply of spare parts seems to be a difficult proposition. Introduction of combine harvester is appropriate for large-scale fields, and for small-scale fields, improved grass cutter machine with cover can be the substitute tool. Regarding rice transplanter, there are cases of its introduction in irrigated rice farming areas, but sophisticated techniques are necessary to produce small seedlings for rice planting. Thus, it seems that the transplanter is currently not suitable for operation in rice-irrigation areas because field leveling is not comparable to that found in Japan.

Conclusions

Although the penetration rate of agricultural machinery in each country is still as low as 10-30%, given the current state of agricultural mechanization, there seems to be potential in each situation. For example, under Kenya's irrigation scheme, the introduction of combine harvesters is growing, and their maintenance system is being set up. This situation will be applied in the future in other irrigation schemes, such as Mbeya and Moshi in Tanzania, and further diffusion of the combine harvester can be expected. If rice cultivation becomes large-scale, opportunities for combine harvester utilization will increase to cope with labor shortage at harvest. On the other hand, the power tiller has the potential in areas with many small farmers. When investigating, there was a case where they improved income by expanding cultivated area by utilizing power tiller. By linking power to other agricultural machinery, the occupancy rate can increase and lead to further income improvement. It is also very useful as a means of transportation and it can be an alternative to donkeys and oxen. It is hoped that the mechanization in each country will be accelerated in the future by framing suitable policies, including agricultural finance.

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Trends in Agricultural Mechanization in Kenya's Maize Production Areas from 1992-2012

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Abstract

Agricultural intensification is key to feed the rapidly increasing African population. While the use of improved varieties has increased substantially over the last twenty years, the use of land-saving technologies such as fertilizer and labor-saving technologies such as mechanization has lagged behind. This study provides a literature review and analyzes the evolution of agricultural mechanization in Kenya, based on four household surveys conducted in Kenya between 1992 and 2012. The results show persistent low levels of agricultural mechanization: in 2012, most farm households still used only hand tools. More than a quarter of farmers (28%) had a plow (either for oxen or tractor), but very few (2%) a tractor. From 1992 to 2012 the percentage of farmers with oxen increased from 17% to 33%, but those with tractors decreased from 5% to 2%. Tractors were most important in the highlands, but animal traction was most important in the dry areas and moist mid-altitude zone. Adoption of tractors increased with income, acreage and age. Adoption of animal traction increased with absentee husbands, income, age, sales of maize, livestock, family size, and access to extension; it decreased with land and with fertilizer use. Mechanization in Kenya is likely to continue depending on animal traction, which is not linked to farm size and complements labor, helps to reduce fertilizer and increase commercial maize production, and has room to grow, in particular in the highlands. Agricultural extension, development projects and research should consider the options in animal traction, and provide training and research on appropriate technologies and implements in areas with sufficient land area.

Keywords: mechanization, Africa, agriculture, intensification

Introduction

Despite recent economic growth in Sub-Saharan Africa (SSA), poverty levels in the continent remain alarmingly high, especially in rural areas. Most people still live on, and from, rural land, but the population is increasing fast, while demand for food and fuel is increasing rapidly, and the increased pressure on the land has led to deforestation and land degradation in many places. To feed a rapidly growing population, agricultural intensification is therefore urgently needed.

Other continents have experienced the green revolution with dramatic increases in agricultural production as well as a reduction in food prices (Evenson & Gollin, 2003), driven by technology and structural transformation, but this has not happened in SSA. While the use of improved varieties has increased substantially, the use of other land-saving technologies (such as fertilizers and irrigation) and labor-saving technologies (mechanization) remains limited. A recent study, covering representative households surveys in six SSA countries found that only one third of the cultivating households apply inorganic fertilizer and the average unconditional nutrient application rate is 26 kg/ha (as compared to 13 kg for the whole of SSA) (Christiaensen, 2017). Based on the same surveys, another study concludes that the use of organic and chemical fertilizers is too low to maintain soil fertility (Binswanger-Mkhize & Savastano, 2017).

Many studies have covered the adoption of improved varieties (Doss, Mwangi, Verkuijl, & De Groote, 2003; Smale & Jayne, 2003) and fertilizer (Jayne, Govereh, Wanzala, & Demeke, 2003) in East and Southern Africa. The return of input subsidies generated a range of studies, documenting that their costs can be high compared to the benefits (Jayne and Rashid, 2013), that subsidies can crowd out the private sector (Xu, Burke, Jayne, & Govereh, 2009) and that they are often used for political purposes (Mason and Ricker-Gilbert, 2013)

Agricultural mechanization in Africa has not received the same attention. The topic drew much interest in the 1980s, when several influential studies, argued that African countries were not yet ready for widespread agricultural mechanization (Binswanger, 1986; Pingali, Bigot, & Binswanger, 1987). Since then, the topic has not received much scientific interest, although the Food and Agriculture Organization (FAO) is trying to revive it (FAO & UNIDO, 2008). Recent studies in Ghana did not provide support for the classic government tractor-providing service program (Diao, Cossar, Houssou, & Kolavalli, 2014; Houssou *et al*., 2013). In Burkina Faso, however, animal traction was shown to increase both labor and land productivity (Savadogo, Reardon, & Pietola, 1998). A recent study in (Baudron *et al*., 2015) argues that sustainable intensification in Eastern and Southern Africa (ESA) will require more power which could be achieved through small, multipurpose power sources such as two-wheel tractors combined with energy saving technologies such as conservation agriculture and an enabling policies, but the number of these devices imported in the region remains small. A study of the Ghana government's Agricultural Mechanization Services Enterprise Centers (AMSEC), based on interviews with service providers, indicates the model is unlikely to be a profitable business model attractive to private investors even with the current level of subsidy, because of the low tractor utilization rate (Houssou *et al*., 2013). In Nigeria, analysis of household survey data shows how current tractor use is associated with input-intensive crop production, albeit with strong regional differences between the north, where it is associated with increased nonfarm income-earning activities rather than area expansion, and the South were it is highly concentrated among medium-scale rice producers data (Takeshima, Pratt, & Diao, 2013). However, no recent studies on agricultural mechanization based on household surveys are available for ESA.

To help the discussion on the possibilities of agricultural mechanization for the intensification of agricultural production in SSA, this study provides a review of the relevant literature, followed by a quantitative evidence of the evolution of farm mechanization in Kenya over the last 20 years, based on four consecutive representative household surveys, all covering the major agricultural zones of the country.

Methods

Conceptual Framework

Intensification of agriculture is generally driven by an increasing population, which requires communities to produce increasing amounts of food on a fixed land area (Boserup, 1965). Technology development tends to follow the direction of the scarcest resources, a process called induced innovation (Ruttan & Hayami, 1984). Mechanization, the replacement of human labor by machinery, tends to occur therefore where land is abundant or labor is scarce, as in many settler communities such as North America, but also under the conditions of large-scale settler farms in East and Southern Africa, in particular in the first half of the 20th century. However, when the population grows rapidly, as is the current case in Africa, land becomes scarce and labor abundant. These conditions are likely to remain until a structural transformation, the movement of large groups from rural to urban settlement and employment, driven by economic development and the creation of job opportunities in the cities. Only when rural labor moves to the cities, and the economy is sufficiently strong to absorb them and pay increasing wages, will labor become scarce in rural areas.

Animal traction has some benefits other than replacing labor: draught animals provide manure to replace expensive mineral fertilizer, and provide transport of inputs and produce within the farm and to and from local market centers. It reduces drudgery and offers an increase in agricultural production above family needs.

Empirical Framework

This paper uses data from four household surveys conducted in Kenya over the last 20 years. We first analyze the use of farm implements in the last survey (2012), and their geographical distribution. Because of the different definitions of variables in different surveys, for analyzing the evolution of mechanization we charted the proportion of farmers who adopted tractors, plows and oxen over time, by agro-ecological zone. In our analysis, adoption of these implements was limited to their ownership, as data on rent or lease of the implements were not available. Only four-wheel tractors were considered, as no data on two-wheel tractors, a recent introduction in the country, were available. Plows for use with oxen as well as those for tractors were included, although the data did not distinguish between the two.

Finally, we use a logistic regression to analyze the factors that affect the adoption of mechanization. In the logistic model, the dependent variable is binary, in this case the adoption (yes or no) of one of the mechanization implements. Formally, the model specifies that the log-odds of the probability of adoption is a linear combination of independent or predictor variables.

In our model, the predictor variables include characteristics of the household head (age, education, and gender) and of the household (available land, labor and livestock), and access to markets and rural services (in particular access to extension and to microcredit).

Data Sources

The data were collected during rural household surveys conducted in Kenya over the last twenty years (1992, 2002, 2010, and 2012). The first three surveys were cross-sectional, while for the last survey the households of the previous one were revisited, with a rotation of 20% of the sample. All surveys were representative of the major maize-growing areas of the country, and used a stratified two-stage design, with agro-ecological zones as strata, sub-locations as primary sampling units, and households as the second stage. Each survey covered more than 1,300 households (**Table 1**, **Fig. 1**).

The first survey was conducted in 1992 by the International Maize and Wheat Improvement Centre (CIMMYT) and the Kenya Agricultural Research Institute (KARI) in the major maize agro-ecological zones of Kenya (Hassan, Lynam, & Okoth, 1998). The study redefined these zones into six major agro-ecological zones for maize production (**Fig. 1**). From the coast moving inland, the lowland tropics can be distinguished, followed by the dry mid-altitudes and the dry transitional zones. These three zones are characterized by low yields, below 1.5 tonnes per ha (t/ha). Although these zones cover 29% of Kenya's maize area, their maize production is only 11% of the country's total production. Central and western Kenya is dominated by the highland tropics (HT), bordered at the west and east by the moist transitional (MT) zone (transitional between mid-altitudes and highlands). These zones have high yields (more than 2.5 t/ha) and produce roughly 80% of Kenya's maize on 30% of Kenya's maize area.

The first survey was conducted in 1992 and covered 79 enumeration clusters, randomly selected from the sampling frame of the Central Bureau of Statistics, with 1407 farmers (Hassan *et al.*, 1998). The second survey, conducted in 2002, covered 185 sub-locations, randomly selected from the 1999 census report (CBS, 2001), and 1800 farmers (**Table 1**).

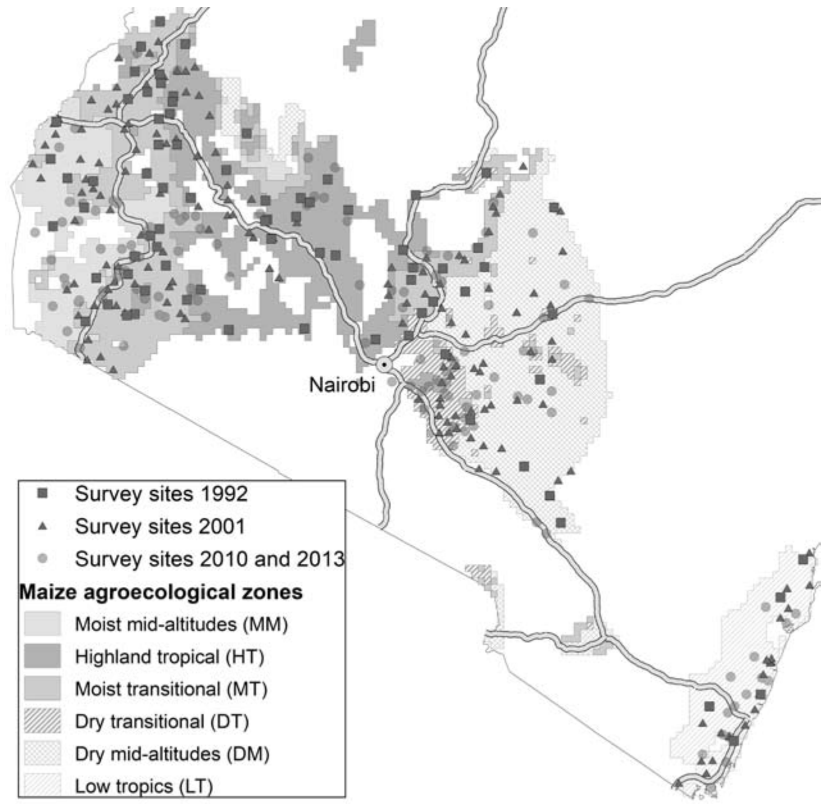

Fig. 1 Map of primary sample units of the consecutive household surveys

Table 1 Sampling design of the four surveys

	1992			2002			2010			2012		
Agro-ecological zone	PSUs	HH/ PSU	HH	PSUs	HH/ PSU	HH	PSUs	HH/ PSU	HH	PSUs	HH/ PSU	HH
Low tropics	5	20	100	20	15	300	15	6	90	15	6	90
Dry mid-altitude	10	18	181	25	8	200	18	12	217	18	12	216
Dry transitional	4	20	80	20	5	100	17	12	203	17	12	204
Moist mid-altitude	9	20	183	25	10	250	20	12	240	20	12	240
Moist transitional	23	18	412	55	10	550	30	12	354	30	12	354
High tropics	28	16	451	40	10	400	20	12	240	20	12	240
Total	79		1,407	185		1,800	120		1,344	120		1,344

HH = number of households in the survey, PSU = primary sampling unit (clusters in 1992, sub-locations in the other years)

The third survey (2010) covered 120 sub-locations, with 1344 farmers. The fourth survey (2012), revisited the same sub-locations of the 2010 survey, and the same households except for a replacement of 20% of the households, randomly selected. This survey therefore had the same number of sub-locations (120) and the same number of households (1,344) as the previous survey.

Background

History of Mechanization in Africa

Agricultural mechanization is the application of mechanical technology and increased power in agriculture, to enhance the productivity of human labor and other forms of capital to achieve results well beyond the capacity of human labor. Mechanization includes the use of tractors as well as animal- and human-powered implements and tools, and internal combustion engines, electric motors, wind energy, solar power and other methods of energy conversion. (FAO & UNIDO, 2008).

Agricultural engineering and mechanization were key enablers for the rise of large-scale industrial agriculture, historically delivering the step changes in productivity per unit of manpower which allowed countries to transform from agriculture to industry-based economies (Beddington, 2010). A fundamental scientific approach in crop science, supported by technology development for mechanization, has made it possible to considerably increase cropping intensities in the major crops of the world (Brussaard *et al*., 2010). Mechanization increases productivity per unit of man power, but it also improves timing, in particular for timely planting, weeding, harvesting, and pest control (Kislev & Peterson, 1981).

Most African countries have economies strongly dominated by the agricultural sector. Agriculture generates up to 50% of the gross domestic product (GDP), contributing more than 80% of trade in value and over half of the raw materials to industries (FAO & UNIDO, 2008). It provides employment for the majority of Africa's people. Despite these contributions, planning for sustainable agricultural mechanization is limited. In many cases where mechanization made a positive contribution to agricultural development, it has been a question of luck, not by credible project or program design (Rijk, 1989).

In spite of the contribution of agriculture to the economy of sub-Saharan Africa over time, there has been a significant decline in mechanization, or at least in the use of tractors and tractor hire services for farming, even among the countries that were the early trendsetters in mechanization, such as Kenya and Zimbabwe. Tractor use in sub-Saharan Africa was at 1.9 per 1000 ha of cultivated land in 1986 and has gradually declined to 1.3 tractors per 1,000 ha in 2002, compared to 9.1 tractors/1,000 ha in South Asia and 10.4 tractors/1,000 ha in Latin America for the same year (Pingali, 2007).

The process of mechanization has progressed from the most elementary devices such as levers to today's sophisticated machines. Throughout this progress, however, the constant purpose has been to supplement or complement human work efforts (Binswanger, 1986). For instance, farmers who embrace mechanization increase the power input to farm activities, they reduce toil in farming, thus making their farm work more attractive; they accomplish tasks that are difficult to perform without mechanical aids, improve the efficiency and timeliness in farm activities, and improve the quality and value of work and the end products, among others (Sims & Kienzle, 2006).

The use of animal traction in Africa started around 6000 BC, as shown in depictions of oxen and plows in Egypt and early Mesopotamian civilizations, some of the earliest records in the world. In North Africa and Ethiopia, animal traction has been a core part of farming and transportation for over 2,000 years. In South Africa, European travelers observed the Khoi-Khoi riding cattle and used them as pack animals in the fifteenth century (Joubert, 1995). In West Africa, the use of horses, donkeys and camels for riding has been popular for centuries, especially in the semi-arid areas (Starkey, 2000). However, in many sub-Saharan countries, especially in the east and the south, manual labor is still the main source of power in agriculture, and draught animals are a relatively recent introduction (Lawrence & Pearson, 2002).

However, animal traction in SSA, apart from Ethiopia, was only introduced during colonial times (Starkey, 2000), and manual labor remains the main source of power in agriculture. It has been argued that an increasing population and increased food demand asks for a more effective use of mechanization, and probably an increase, in particular for draught animals, especially in areas where tractors are not appropriate (O'Neill & Kemp, 1989). Animal power has a potential to enhance farmers' ability to use renewable practices such as manure, crop rotation, ridging and other renewable practices. They allow the cultivation of larger areas, and increase household production, food security, and the likelihood of a marketable surplus (Bishop-Sambrook, 2005).

In the late 1990s, 65% of the cultivated area in SSA was prepared by hand, 25% by draught animals and 10% by tractors (FAO & UNIDO, 2008). In Kenya, the main draught animals are oxen and donkeys, which are well-distributed throughout the country. Tractors were only introduced shortly after World War II and, in the first two decades after independence, the government promoted motorized mechanization through state-sponsored tractor-hire and -credit schemes, to increase crop production (Guthiga, Karugia, & Nyikal, 2007).

The adoption of tractors in SSA went through roughly three phases over the period between 1945 and 1981. These phases were significant in increasing the number of tractors in use, with intermediate periods of slow growth (Pingali, 2007). In the first phase (1945-1955), the use of tractors was promoted in several countries under their colonial regimes, including Zimbabwe, Kenya, Zambia and Malawi. These can be labeled the first generation of tractor users, and adoption spread from settler farms to farms owned by Africans. In the second phase, between 1958 and 1970, mechanization was sponsored by newly-independent countries such as Tanzania, Ethiopia, Ghana, and Cote d'Ivoire. In many of these countries, tractors were provided through cooperative, state farms or tractor-hire services. In the third phase (1970-1980), exporters of oil and other resources, such as Nigeria, Cameroon and the Democratic Republic of Congo tried to re-distribute the export profits to rural areas. Tractors were provided to farmers through either subsidized credit schemes or state-sponsored hire schemes (Pingali, 2007).

The adoption levels of tractors declined after 1981, however. The collapse of the government-sponsored tractor-hire services was mainly attributed to poor performance, lack of infrastructure and poor management of the schemes. The area cultivated per machine were small and fixed costs were high, while lack of technical know-how and spare parts resulted in poor maintenance and expensive and lengthy repairs (Bishop-Sambrook, 2005). Further, most farmers could not afford tractors, and organization of cooperatives or farmer groups to access credit and obtain tractors was rare (Lamidi & Akande, 2013).

It has been argued that tractors could have a negative impact on employment in the agricultural sector and would therefore not be suitable to densely-populated areas with labor surpluses, especially in SSA, although unemployment also depends on many other factors, in particular the policy environment (Pingali, 2007). Loss of employment was most pronounced under inappropriate mechanization policies in areas where it was not needed. In many countries, government tractor services collapsed after externally-funded projects ended (Pingali, 2007). After the collapse of tractor projects, more attention was given to drought-animal power as a more sustainable option. In Kenya, such a program was established in 1970, covering the selection and training of draught animals, farmer training and development of specialized equipment (Onyango, 1990). However, efforts to accelerate the use of mechanization produced mixed results. Compared to other regions, Africa did not have large-scale investments in agricultural infrastructure, such as irrigation and other inputs needed for intensification (FAO & UNIDO, 2008). Further, past agricultural mechanization efforts in developing countries have been criticized because of ineffective programs, and for increasing rural unemployment and causing other adverse social effects (Rijk, 1989). For maize production in East Africa, the promotion of mechanization projects only saw limited success in Kenya, but not in Tanzania (Anthony, 1988).

In Ghana, demand for mechanized farming operations, particularly plowing, has emerged even among smallholders, suggesting that supply issues may now be the main constraint to successful mechanization (Diao *et al.*, 2014). However, the agricultural mechanization service centers that the government promotes fail to use tractors services with sufficient intensity, and direct importation of agricultural machinery by the government inhibits the importation of more appropriate and affordable machinery by the private sector for its use in a hiring-out services. The government's service centers are not a profitable business model attractive to private investors, even with the current level of subsidy (Houssou *et al*., 2013).

Not all mechanization schemes in Africa failed; some were successful, particularly in combination with irrigation. The Gezira Scheme in Sudan dates back to 1924 and by the 1970s, 100,000 tenant farmers were cropping 760,000 ha with the assistance of mechanized cultivation services (FAO & UNIDO, 2008). In Tanzania, tractors were successfully introduced in the Morogoro region and single axe tractors in the Mbarali district (Shetto, 2007). In West Africa, animal traction was successfully introduced in the cotton production areas, and spread rapidly in the 1980s and 1990s (Blench, 2015; Tefft, 2010). In Burkina Faso, animal traction was found to greatly improved labor productivity, but also land productivity, in particular for cash crops (maize and cotton) (Savadogo *et al*., 1998).

Still, mechanization on smallholder farms in SSA remains limited, and grain milling is often the only fully mechanized operation (Kienzle, Ashburner, & Sims, 2013). Examples of areas where animal power is used for milling are Somalia and Chad (Starkey, 2000), but in most countries diesel-powered mills are common. Mechanization is also increasingly adopted for irrigation, mostly with relatively low-cost small motor pumps (Kienzle *et al*., 2013) and sometimes with animals, as in Egypt (Starkey, 2000). The success of mills and pumps is their relatively low cost and easy maintenance (Kienzle *et al*., 2013). Smallholders also use animal power for threshing cereals, as in Tunisia and in Ethiopia (Starkey, 2000).

Large scale farming, in contrast,

has seen higher levels of mechanization at all stages of production. For example, irrigation schemes in Sudan (the Gezira scheme) are highly mechanized. Similarly, in sugar cane production Kenya and Tanzania, land preparation, cane loading, and cane transport to the factory are largely mechanized (Kienzle *et al*., 2013). Another example is wheat farming in Kenya, with tractors for cultivation and planting, spraying equipment, and combine harvesters, mostly by large-scale farmers with their own machinery (Longmire & Lugogo, 1989). Small-scale wheat farmers do not own machinery and have to hire contractors or use manual labor (van Eijnatten, 1976).

Recommendations from the literature

This literature review indicates that both the government and the private sectors have clear, but distinct, roles to play in sustainable mechanization. The role of the government lies in education and training, in the creation and funding of relevant research institutions, and the dissemination of information on mechanization (FAO & UNIDO, 2008; Mrema, Baker, & Kahan, 2008; Zewdie, Wallace, & Kic, 2015). Further, governments should facilitate trade relationships with new suppliers of technology and equipment and help in maintaining standards (FAO & UNIDO, 2008).

The private sector, on the other hand, is better equipped to regularly provide farm inputs including farm machinery and its support services. Once economic conditions have evolved to create an effective demand for machinery, private firms respond rapidly (Binswanger, 1986). Decisions on which operations to be performed, which prices to be charged, and so on, are better made by the private sector than by the government. The private sector has clear incentives for the mechanization of agriculture: more mechanization implies a higher demand for their services and result in higher revenues (Pingali *et al*., 1987). Government can help the private sector by developing and supporting the market for hiring-out, for example by the development of mechanized service hiring market through medium and large scale tractor-owning farmers as in Ghana, but the direct importation of agricultural machinery by the government inhibits imports of appropriate and affordable machinery (Diao *et al*., 2014).

The economic costs of using tractors, animals or human labor is determined by the relative costs of labor and capital, the interest rate, the utilization of capacity, the farm size, the availability of fodder, the comparative maintenance costs of animals and tractors, and the difficulty of obtaining spare parts, fuel, and repair services for the tractors or veterinary services for the animals (Pingali *et al*., 1987). Therefore, farmers need to calculate and compare the costs and benefits of alternative options and find those best suited to their needs. However, draught animal power, tractor power and human power should be taken as complimentary sources of power for agriculture production and not as mutually exclusive ones. In Burkina Faso, for example, of-farm income was a major factor that allowed farmers to invest in animal traction (Savadogo *et al*., 1998).

The development and modernization of Africa's agriculture needs appropriate agricultural policies, and agricultural mechanization policy needs to be placed within an overall agricultural growth strategy (Pingali, 2007). It is imperative for African leaders and policy makers to understand the importance of mechanization for Africa's future. There should be concerted efforts by all stakeholders to accelerate the rate of adoption of mechanization by farmers in sub-Saharan Africa, whether through drought animals or tractors. These efforts to accelerate mechanization will require substantial long-term political and financial commitments, which ought to address the biting problems in the agriculture sector and help to improve the prospects for African agriculture and farmers (Mrema *et al*., 2008). In the meantime, it is important to look at available information to guide policies, as we do in the next section.

Results

Farm Implements Currently Used

The proportion of farmers who used different implements in 2012 reveals the very limited extent of agricultural mechanization in Kenya (**Fig. 2**). Most farm implements used were hand tools, and most households owned at least some pangas (machetes), hoes, axes, spades or shovels. More than half of the households owned a fork hoe or a slasher. The most popular mechanical device was the bicycle, owned by almost half of the households (48%). The most popular modern farm implements were the knapsack sprayer (owned by 46% of respondents) and the wheelbarrow (45%). As to mechanization, more than a quarter of farmers owned an ox-plow (28%), but few had an oxen or donkey cart (8%), and even fewer had a push cart (2%). Tractors were rare, owned by 2% of the farmers in the survey owning them.

Devices to generate electricity were more popular than tractors: 17% of respondents had solar panels and 6% had a generator. For transport, apart from the bicycle, only a few farmers owned vehicles and a few households had a motorbike (10%) or a car (5%).

Evolution of Agricultural Mechanization

Plotting the evolution of agricultural mechanization in Kenya over the last 20 years shows how the levels of adoption were never high (**Fig. 3**). Oxen were introduced by European and South African settlers in the early 20th century, who switched to tractors over time. After independence, the large settler farms and their equipment were purchased by African farmers and the upcoming elite (Jones, 1965). The latter, however, never had many tractors, and tractor use has been decreasing. In 1992, only 4% of farmers owned tractors, and in 2012 less than 2%. During this period, there were many more farmers with plows than with tractors, and their number has been steadily increasing, from 12% to 28%. Similarly, the proportion of farmers owning oxen increased steadily from 17% to 33%. There was a dip in oxen ownership in the third survey, in 2010, likely because of a serious drought just before the year of the survey.

Plotting the results separately for each year and by zone shows the large differences in mechanization levels, both for tractors and animal traction, between the agroecological zones (**Fig. 4**). The relative importance of tractors and animal traction over the different zones did not change over the years. Tractors have always been most important in the highlands, while oxen and oxen plows were more popular in the dry mid-altitudes and, to a lesser extent, the moist mid-altitudes. Most tractors were found in the highlands, with only a few in other zones, likely influenced by its colonial his-

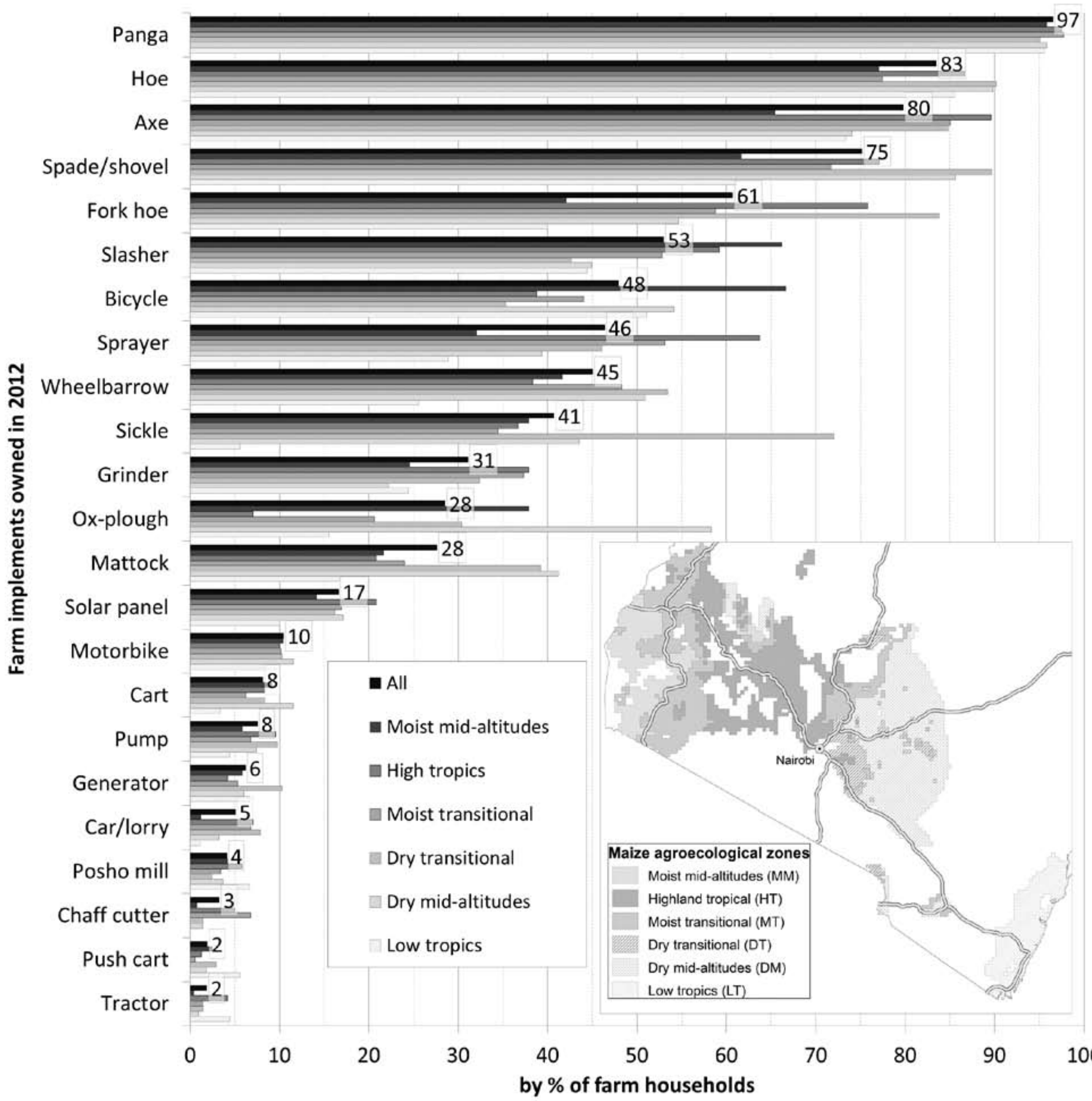

Fig. 2 Farm implements used, by agro-ecological zone (farm households of 2014)

tory of large-scale, capital intensive farms. Only in the last survey did tractors show up in the coastal lowlands. Likely, the presence of tractors in the highlands is influenced by colonial history, which favored large-scale, capital intensive and commercial farming. Ownership of plows is, understandably, strongly correlated to ownership of oxen. Especially in the dry zones, many farmers have oxen and plows. The popularity of oxen in the dry areas likely is affected by the lower population density, so farms have larger land areas for both farming and pasture and have more cattle from which to draw oxen. Similarly, farmers in the moist mid-altitudes tend to have more cattle, which affect the adoption of animal traction. The high tropics, on the other hand, have the lowest levels of animal traction, despite its high potential and large available land areas. This might be affected by its history tractors and the resulting presence of tractors for hire. Also, the highlands tend to have only one long rainy season, so plowing is only needed once a year, as compared to the other zones which tend to have two rainy seasons and therefore, need to prepare land and plow twice a year.

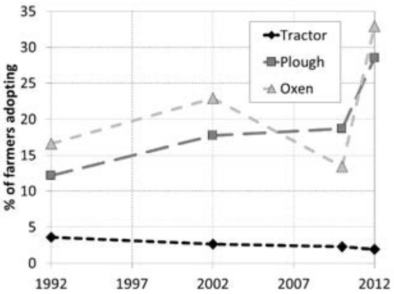

Fig. 3 Evolution of farm mechanization from 1992 to 2012

The analysis shows that few farmers owned carts, for donkeys or oxen: 12% in the dry mid-altitudes and less than 10% in all other zones. The proportion of farmers with carts did not increase much over the years.

Plotting the evolution for the different implements for each zone shows the similarity of the trajectories in the different zones (**Fig. 5**). With few exceptions, the proportion of farmers who own tractors has been declining, while the proportion of those with oxen and plows has been increasing. One exception is the coast, where several farmers obtained tractors between the last two surveys. Another exception is the reduction in the proportion of farmers with oxen or plows in the dry transitional zone: there was a strong increase in 2001, but was followed by a decrease in 2010, and then finally an increase up to the last survey.

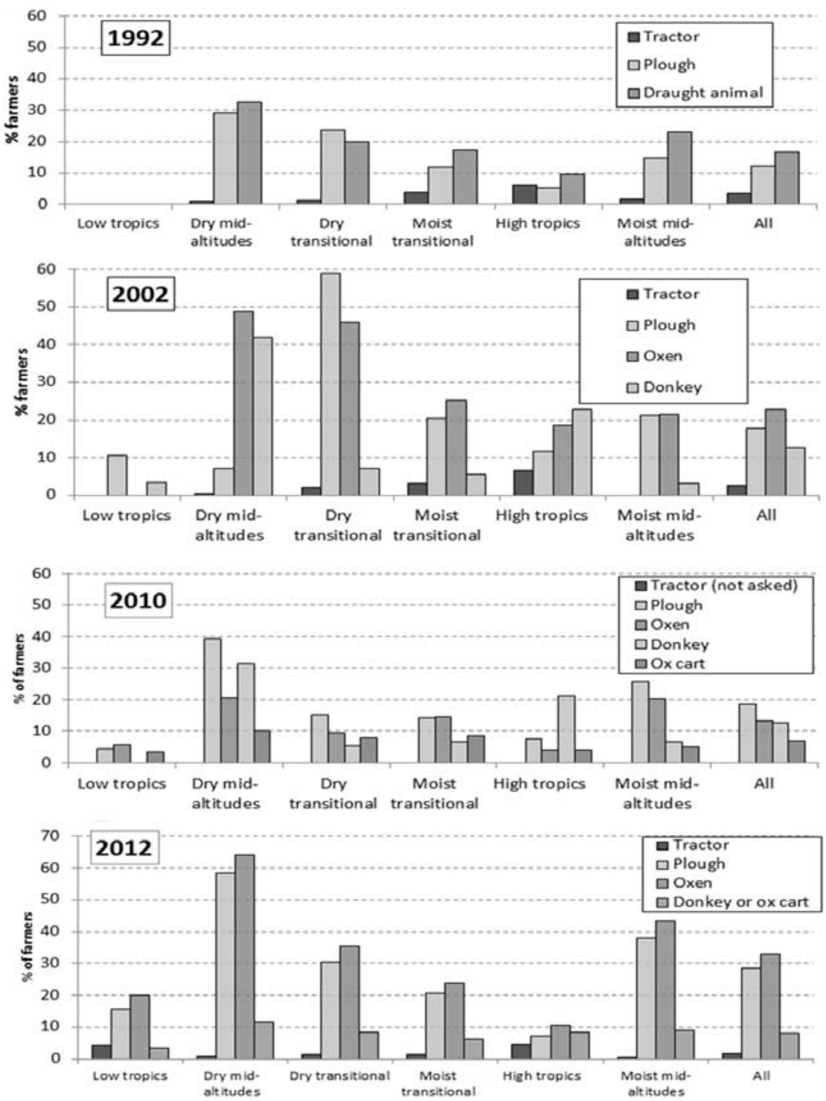

Fig. 4 Evolution of farm mechanization from 1992 to 2012, by agro-ecological zone and year

Factors Affecting the Adoption of Farm Mechanization

A logistic model was estimated to analyze which factors affection the adoption of agricultural mechanization. Three different dependent variables were used for the analysis: ownership of tractors, trained oxen or plow (for either tractor or oxen), all expressed as binary variables (yes = 1, no = 0). The results show that the model for tractors was very different from that for oxen and plows, which had similar results. Only two factors significantly affected both the tractor and the oxen/

plow models: ownership of both implements increased with the age of the household head and with household income. Total available land per household affected ownership of both tractor and oxen but in different ways: it increased the likelihood of owning tractors, but decreased ownership of trained oxen. Similarly, the agroecological zones mattered, but where farmers in the highlands had more tractors and fewer oxen, those in the dry and moist transitional zones had more oxen and fewer tractors.

Clearly, the adoption of tractors and of oxen and plows follows different mechanisms. The adoption of tractors is affected by age: older farmers are more likely to have tractors. This is consistent with a decline in tractor ownership over time. Further, tractor ownership increased with available land and capital, which is also understandable: tractors need sufficient land to justify their use and require a substantial amount of capital. After taking into account those factors, there are still regional differences: the high tropics, as well as the low tropics, have significantly higher proportions of farmers with tractors than the other zones. The higher adoption of tractors in the highlands clearly originates in its colonial history

Ownership of oxen was affected by household composition. Households with absentee- husbands were more likely to have oxen. This might be because of remittances from the husband or because the household is short of labor, although both arguments are problematic: income does not increase the probability of owning oxen, while available labor reduces this probability. The latter indicates that oxen power compliments labor rather than substitutes for it. Further, the number of tropical livestock units owned increased the probability of adopting oxen and plows. Likely it helps to own more cattle, from which oxen can be pulled. More land, on the other hand, decreases the probability of having oxen, but does not affect plows. This is counterintuitive; we would have expected larger farms to be more likely to own oxen.

The number of extension contacts is an important factor in the adoption of mechanization: an increase in one extension contact over the last year increases the probability of owning oxen or plows by 1%. Land ownership (in % of land owned) does not seem to make a difference. The use of fertilizer, or at least top dressing, is negatively correlated with the adoption of animal traction: likely when a household has oxen there is less need for fertilizer. Marketing of maize, on the other hand, increases the adoption of animal traction, indicating commercially-oriented farmers are more likely to invest in animal traction. After taking into account the above factors, the zones are still important factors in the adoption of animal traction.

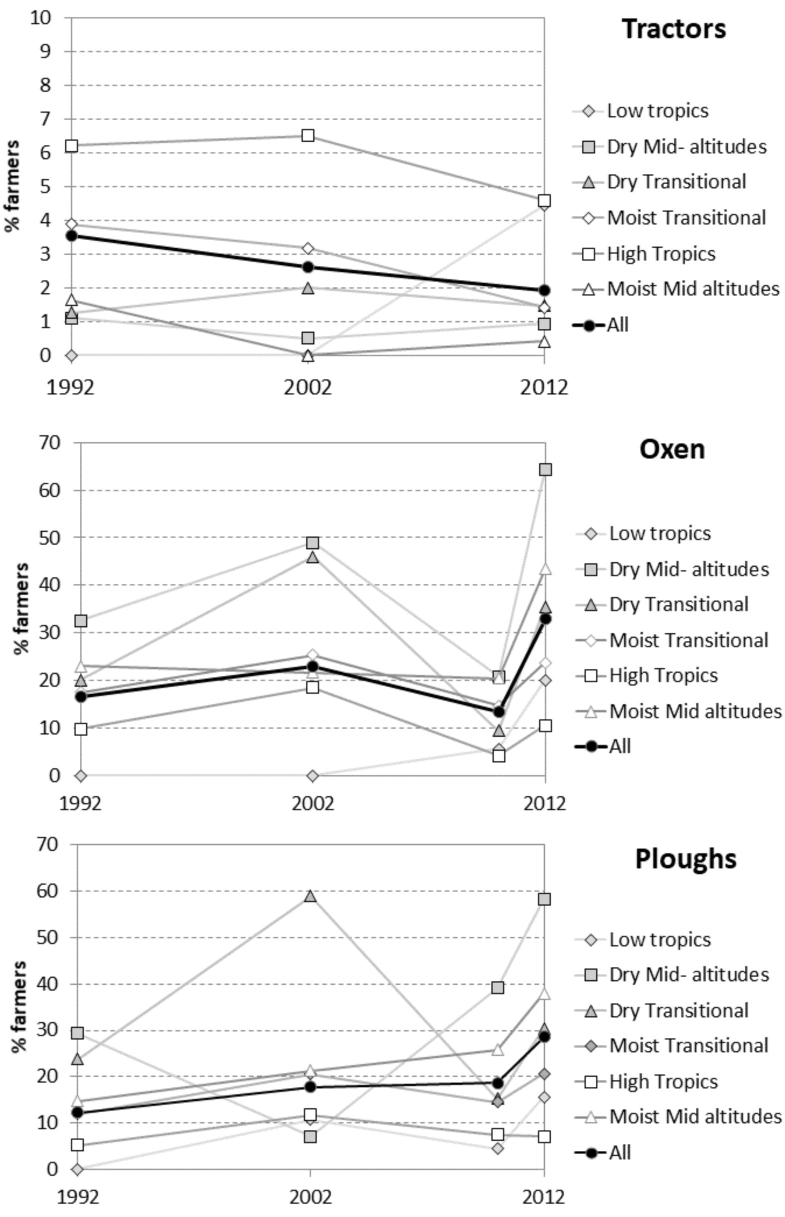

Fig. 5 Evolution of farm mechanization from 1992 to 2012, by year and by agro-ecological zone

The drylands and the moist mid-altitudes have higher adoption levels than the low tropics (the base), likely because they have more cattle and less people. The high tropics have lower levels of animal traction, likely because of its historic use of tractors (**Table 2**).

Conclusions

This study documents the low levels of agricultural mechanization in Kenya. In 2012, most farmers used only hand tools, and slightly less than half owned a bicycle, a knapsack sprayer or a wheelbarrow. Slightly more than a quarter of farmers (28%) owned a plow, and very few (2%) owned a tractor. None of the interviewed farmers owned two-wheel tractors. From 1992 to 2012, the proportion of farmers with trained oxen increased from 17% to 33%, while the proportion of those with tractors decreased from 5% to 2%. Tractors were most important in the highlands, while animal traction was more popular in the dry areas and moist mid-altitudes (around Lake Victoria). Relative differences between zones have remained over the years, and all zones have followed the same trend of increased animal traction and decreased adoption of tractors. Adoption of tractors and animal traction follow distinctly different models, as expressed by the different factors affecting them. Adoption of tractors increased with household income, acreage and age of the household head. The adoption of animal traction, on the other hand, increases with income and age of the household head, but decreases with land area. Further, adoption of animal traction is higher in households where the husband is away, and increases with sales of maize, livestock, family size, and access to extension. Finally, adoption of animal traction is negatively correlated with the top dressing of fertilizer.

The four different household surveys over the last 20 years offered good insights into the evolution of agricultural mechanization in the different zones, despite the first three surveys having independent cross-sectional designs. It remained a problem that different surveys use different tools and definitions for

Table 2 Factors affecting the adoption of farm mechanization (farm household survey of 2012)

		Tractor			Trained oxen			Ox plow		
Dependent variables		Coef.	Std. Err.	P > z	Coef.	Std. Err.	P > z	Coef.	Std. Err.	P > z
Head	Constant	-7.29	1.98	***	-4.55	0.83	***	-4.21	0.74	***
	Age of household head (years)	0.04	0.02	*	0.00	0.01		0.02	0.01	***
	Household head is male	-0.37	1.05		0.54	0.45		-0.25	0.39	
	Head education (years)	0.04	0.04		0.01	0.02		0.03	0.02	*
Marital status	Married but spouse away	0.59	0.91		0.88	0.32	***	0.45	0.30	
	Divorced/separated	0.00	(empty)		0.18	0.80		-1.00	0.78	
	Widow/widower	0.38	1.06		0.50	0.46		-0.34	0.41	
Household	Adult equivalent	0.14	0.09		0.15	0.04	***	0.15	0.04	***
	Tropical livestock units	0.00	0.02		0.16	0.02	***	0.11	0.02	***
	Total land (acres)	0.03	0.01	**	-0.02	0.01	***	0.00	0.01	
	Number of extension contacts	0.00	0.01		0.01	0.00	***	0.01	0.00	***
	Total income (KES)	0.81	0.33	**	-2.18	0.48	***	-1.41	-2.18	***
	% land owned	0.56	1.01		0.34	0.40		0.53	0.35	
	planting fertilizer (1 = Yes; 0 = No)	0.16	0.73		0.10	0.25		0.10	0.22	
	Topdressing fertilizer (0 = No; 1 = Yes)	0.98	0.68		-0.70	0.24	***	-0.56	0.21	***
Agro-ecological	Dry mid-altitude	-1.95	0.97	**	1.58	0.46	***	2.19	0.39	***
	Dry transitional	-2.25	1.01	**	0.80	0.49		1.11	0.41	***
	Moist transitional	-2.51	0.89	***	0.34	0.47		0.40	0.40	
	High tropics	-1.07	0.76		-1.69	0.58	***	-1.75	0.51	***
	Moist mid-altitudes	-2.54	1.17	**	1.07	0.46	**	0.90	0.39	**
Marketing	Distance to main market (km)	0.02	0.02		0.00	0.01		-0.01	0.01	
	Percent of own maize sold	1.03	0.80		1.64	0.32	***	1.51	0.29	***
Model	Number of observations	1,111.00			1,128.00			1,128.00		
	Pseudo R2	0.26			0.26			0.24		
	Log likelihood	-80.48			-427.58			-512.80		

data collections. The experience gained with this analysis, however, shows how future surveys can be improved by harmonizing the variables. In particular, a distinction should be made between ownership of, access to and use (through ownership or rental services) of the different farm implements and draught animals involved in agricultural mechanization. Further, within the different implements a distinction should be made between oxen and tractor plows, and between different cart types (oxen, donkey or hand carts). Ownership and use of weeding implements, to be used with draught animals, and shelling equipment should be included. A distinction should be made between oxen for fattening and oxen trained for draught, and ownership of donkeys should be included.

Further, household surveys typically ask about farm implements and draught animals, which ignores other types of mechanization. For example, most households have moved from manual to mechanical milling, but mills are typically owned by a few small businesses located in towns and market places, but do not frequently show up in rural household surveys (only 4% of those owned mills in 2012). The presence of such services (and also electricity and irrigation) would be easier to observe through community surveys, while their use would be best observed through household surveys.

Our results show that agricultural mechanization is only slowly making progress in Kenya, but through animal traction rather than tractors, and this trend is likely to continue. Promoting tractors does not seem advisable, at least not ownership by maize farmers. Tractors are expensive and fuel prices are steadily increasing. Further, the population in Kenya is growing rapidly and most of the population is still living in rural areas, reducing the availability of agricultural land per person and therefore farm size, and suppressing rural wages. As a result, the proportion of farmers owning tractors is decreasing and is likely to decrease further. Tractor rental services, on the other hand, might provide access to mechanization without requiring tractor purchase, but our data did not include information on this. While two-wheel tractors are substantially cheaper than four-wheel tractors, no farmers in the survey owned or used any. The arguments against them are similar to those against four-wheel tractors, so their profitability needs to be carefully assessed and compared to animal traction and manual labor. Again, hiring services might provide a solution and should be considered for further study.

These results from Kenya align with the conclusions of earlier studies (Pingali *et al.*, 1987) that the farming systems in Africa have not yet reached the intensification levels suitable for investment in tractors. Similarly, they conform the results from West Africa (Blench, 2015) that the farming systems, or at least some of them, are more suited for animal traction. Despite the increased interest by farmers, animal traction has been receiving little attention from rural development projects and extension agencies. In our analysis, animal traction is not linked to farm size; it does not reduce labor but rather complements it; it helps reduce the use of chemical fertilizer and helps to engage in commercial maize production. Moreover, there is still a large potential for expanding animal traction, particularly in the highlands. While tractors were popular in this zone, likely for historical reasons, animal traction should be given more attention: large land areas are still available, for both crop production and pasture, the population density is low and commercial maize production is important. Contact with extension increases the probability of adoption, so continued training of trainers, and research and dissemination of locally adapted implements should be encouraged. Animal traction is not indicated, however, in areas with high population density, low land areas per household and low availability of pasture, which would include most of the moist transitional zone.

It was concluded that despite the seemingly more advanced nature and attractiveness of tractors for rural development, the future of agricultural mechanization in Kenya lies in the promotion of animal traction, at least in the short- to medium-term, and in areas with sufficient land area.

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The Current Situation and Perspectives Regarding Agricultural Mechanization in the Republic of Mozambique

by

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Abstract

This article presents an overview of the current status of agricultural mechanization in the Republic of Mozambique and the main agricultural programs supported by the government through the Ministry of Agriculture and Food Security and the private sector. We analyzed percentages of farming households using animal traction and tractors across provinces and years and the number of tractors in the country.

Keywords: agricultural mechanization, Mozambique, animal traction, agricultural machinery market, service centers

Introduction

Agriculture plays an important role in Mozambique's economy. This sector accounts for 23% of the GDP and accommodates a high percentage of the rural labor force (68% of the country's total population is rural). The annual average growth rate of the agricultural GDP, which is 7%, can be attributed mainly to the expansion of agricultural land used for the cultivation of staples such as maize, rice, cassava and agricultural land concessions for planting sugarcane, bananas, and other crops (National Directorate of Agriculture and Silviculture, 2017).

There are 36 million hectares of arable land in Mozambique, but only 1% of this land is currently under cultivation. Of the total arable land, 3.3 million hectares have irrigation potential, but only 14% of this area is being appropriately exploited (Minister of Agriculture and Food Security of Mozambique [MASA], 2016).

The latest agrarian census indicates that more than 90% of farmers in the country are small and medium-sized, with average areas of cultivation ranging from 1 to 1.5 ha. Subsistence agriculture entailing the use of rudimentary technologies is practiced by the vast majority of farmers within household units. Moreover, studies have shown that the country's capacity to implement a mechanization process capable of boosting agricultural production and productivity is weak because of inadequate machinery and equipment available within this sector.

To position Mozambique within the ranks of international suppliers of food products, the government is promoting the establishment of agricultural machinery centers. These centers are expected to provide the necessary solutions for increasing production and productivity, while also facilitating experience sharing between farmers to enhance their understanding and ability to adapt to the current reality.

The aim of this study was to analyze the current status of agricultural mechanization, and the distribution of households using animal traction and tractors within Mozambique. We assessed the current implementation status of Mozambique's agrarian mechanization program and the marketing of agricultural machinery within the country.

Materials and Method

Mozambique is located on the southeastern coast of Africa. It covers an area of 801,590 km^2, including 2,470 km of coastline adjoining the Mozambique Channel and the Indian Ocean (**Fig. 1**). Elevation increases from the coastal plains in the east to the lower and middle plateaus and mountainous areas in the west.

To analyze the status of agricultural mechanization in Mozambique, we collected data from various sources on key stakeholders in the country's agricultural mechanization subsector. These stakeholders included private sector actors and relevant government staff engaged in the planning, implementation, monitoring, and evaluation of mechanization initiatives in the country. Secondary data were obtained from official publications, published articles journals, and documents available on the Internet. While writing this article, we obtained updated material from the Ministry of Agriculture and Food Security (MASA). The analysis is based on a study of relevant documents, government program related to agricultural mechanization sector and official statistics data published by the Ministry of Agriculture and Food Security.

Results and Discussion

Animal Traction in Mozambique

Given Mozambique's significant cultural, socioeconomic, and climatic diversity, farmers' use of animal traction varies by region. There are some general factors that are known to constrain livestock development in Mozambique, such as the presence of Tsetse flies and ticks as well as inadequate pasture. However, the identification of other contextual factors that lead to an uneven distribution of cattle, and consequently influence the use of animal traction, is critically required. There are certain areas where farmers refuse to restock animals, even when this service is freely available, because of their fear and superstitions concerning witchcraft. Because little is known about the "national picture," a multi-disciplinary study is necessary to provide information required for the successful promotion of animal traction. Animal traction is a multidimensional issue and should not be perceived as being simply an agricultural technology. An inquiry on the use of animal traction among farmers in Mozambique, conducted at the grassroots level, should be undertaken by multidisciplinary teams to identify specific actions adapted for each region, province, or district (MASA, 2016).

Fig. 2 shows percentages of smallholder farmers using animal traction for tillage by province and year. Evidently, adoption rates are almost nonexistent in northern Mozambique. Moreover, there was a sharp decline in animal traction usage between 2003 and 2005 in Tete and a sharp increase in usage in Sofala in 2007 and 2008 (MASA,

Fig. 1 Map of Mozambique. Source: United States of America Embassy (2010).

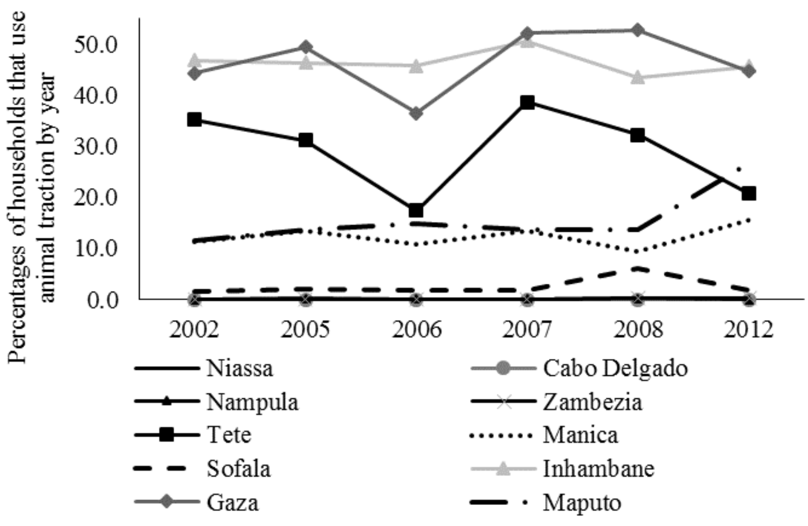

Fig. 2 Percentages of households using animal traction by province and year. Source: Ministry of Agriculture, National Agricultural Surveys (2012).

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Tractor Services in Mozambique

Tractor services are limited in Mozambique. Some large-scale farmers provide land preparation services to neighboring smaller-scale farmers, typically after they have plowed and tilled their own fields. As farmers with larger farms generally plow their own land first, land preparation in other farms where plowing is done with hired tractors is delayed. This delay, in turn, affects the timeliness of planting and may lead to reduced yields. Some development programs such as USAID's Agri-Futuro project have been providing financial aid to selected farmers to purchase tractors for their own use and as an incentive for providing tillage services to neighboring farmers (World Bank, 2012). Within its tractor support programs, the government has specifically targeted service providers, namely, Italian Aid, Plano de Acção da Produção Agrícola, and Zambezi Region Development Authority (GPZ) that can potentially hire out tractors (World Bank, 2012).

Useful Lives of Tractors in Mozambique

Assuming that they are regularly maintained, most tractor brands have an estimated functional lifespan of 10 years. Observers in the field have reported a range of 5-15 years of service, with 7 years being typical for tractors owing to below optimal maintenance. Some commercial farmers who were interviewed in Manica Province estimated a range of 700-1,000 hours of operation for tractors that were used for routine farm operations throughout the year. Respondents in other parts of the country estimated a range of 600-1,100 hours. The mean value obtained from these ranges was 850 hours per year, and the average calculated from estimates provided for different agricultural production zones in Mozambique was 870 hours. The proportions of time allocated for land preparation and transport and other operations were 63% and 37%, respectively. Within farms, the uses of tractors include land preparation (plowing and tilling), transportation of farm inputs and outputs, and powering of other agricultural machinery, such as threshers or shellers. On some commercial farms, tractors are also used for seeding and/or weeding (Ministry of Agriculture/National Directorate of Agrarian Services, 2012).

Distribution of Tractors by the Government

The government plays an important role in the agricultural mechanization of the Republic of Mozambique through its purchase and distribution of tractors within the country. It purchases particular brands of tractors from local dealers, and commencing from 2005, it has been using state funds to purchase tractors that are distributed through Ministry of Agriculture and Food Security, namely the Agrarian Development Fund (FDA). In 2005, the government imported 98 tractors for distribution through the FDA. The main areas of distribution of these tractors were Maputo (40%), Gaza (21%), and Nampula (15%). Although the government does not appear to have imported tractors in 2006 and 2007, in 2008 it imported 50 tractors that were distributed in Beira and Nampula through the FDA. These imported John Deere, Massey Ferguson, and New Holland tractors were valued at US$1.7 million, with the average cost of a tractor being US$34,654. In 2009, the government imported a further 50 tractors through Plano de Acção da Produção Agrícola, and in 2010, the number of imported tractors rose to 330 units. One-third of the imported tractors were purchased by the Italian government through the Commodity International Development Association Project. Banco Comercial e de Investimentos was awarded a contract to lease tractors. Subsequently, the regional distribution of these tractors was more balanced than it was in earlier years—74% went to Inhambane, Manica, Cabo Delgado, Zambézia, and Nampula. In 2010, the GPZ purchased 220 more tractors from China as part of a government-to-government deal (MASA, 2011).

The specific objectives of each government-supported tractor scheme determine who the beneficiaries are. Thus, the aim of the Italian Aid Program has been to increase the production of irrigated crops, primarily rice (**Fig. 3**). Consequently, the beneficiaries of this program are farmers' associations, cooperatives, and Mozambican companies with access to irrigation that are producing predetermined priority crops (especially rice) as well as private companies interested in providing tractor hire services (World Bank, 2012).

Private Sector Participation in the Agricultural Machinery Market

Tractors can be imported freely by private individuals and companies intending to resell them. An analysis of tractor sales by major distributors during the period 2008-2010 showed that the bulk of sales were made to public institutions (**Fig. 4**). Demands from private operators have been generally low because of the low level of commercial farming activities in the country as well as high financing costs, which are widely considered prohibitive, ranging from 23% to 30% per annum (World Bank, 2012).

Mozambique's National Agricultural Mechanization Program

According to the MASA, the national agricultural mechanization program will benefit 35,000 farmers through the establishment of agricultural service centers (CSAs) dispersed across the country. CSAs are aimed at making mechanized agricultural services more accessible to farmers. On average, each CSA covers an area of 1,600 ha and has an efficiency rate of at least 80%. Through the FDA, the government has established 91 CSAs covering all of the provinces in the country. Each CSA is equipped with six tractors as well as agricultural tools for ploughing, harrowing, fertilizing, sowing, and harvesting (MASA, 2016). This equipment is a component of the "More Food Program," which is aimed at raising productivity and transforming subsistence agriculture into commercial agriculture. Under this program, which is valued at US$97 million, a total of 513 tractors and more than 2,000 agricultural implements have been provided.

The More Food Program has been implemented by the Mozambican government, with the support of the Brazilian government and the FAO, to stimulate agricultural development. This program entails the Strategic Plan for the Development of the Agrarian Sector 2011-2020, which is aimed at achieving an annual growth rate of at least 7% for the Mozambican agricultural sector and an increase of 25% relating to cultivated areas devoted to food produce. To accomplish this objective, the government of Mozambique has been acquiring agricultural equipment from Brazil and in 2017, it finalized a purchase agreement with LS Tractor for 513 model P80 tractors (FDA, 2017).

Development of Networked Services for Mechanized Agriculture

The initiative to establish service centers developed and operated by the state through public-private partnerships is expected to stimulate the private sector to establish service centers that can effectively promote the government's mechanization program (MASA, 2017).

Overall Budget for the Mechanization Program

The agricultural mechanization plan is aimed at increasing production and productivity through efforts to improve the quality of agricultural operations and save energy throughout production and processing cycles for agricultural products. Accordingly, the Council of Ministers of the Republic of Mozambique approved a budget estimated at US$68.8 million for enabling the construction of infrastructure and the acquisition of necessary equipment (MASA, 2017).

The Use of Tractors for Tillage by Smallholder Farmers in Rural Mozambique

The more urbanized but less productive provinces of Maputo and Gaza have higher proportions of households that use tractors. **Fig. 5** shows percentages of tractor users in Mozambique. The highest concentrations of these farmers are in Maputo and Gaza, accounting for 63% of the less than 2% of smallholder farmers who use tractors in the country Cunguara *et al.* (2016).

Baudron *et al.* (2015) found that over the last three decades, farm power, both in terms of available tractors and draught animals per unit area (ha) of agricultural land in Mozambique has been stagnating. Consequently, they argue that farm power represents a major factor limiting increased productivity. Constraints to acquiring farm power may delay land preparation and planting, which often result in severe reductions in yields. Thus, while there is a need to increase farm power among smallholder farmers in Mozambique, the choice of appropriate mechanization requires careful consideration.

Conclusions

The main implementation mechanism for achieving agricultural mechanization in Mozambique is service centers established to promote mechanization in areas that have agricultural potential and potential beneficiaries of services relating to mechanization. However, because these farmers are dispersed in Mozambique, the service centers need to be reorganized to make

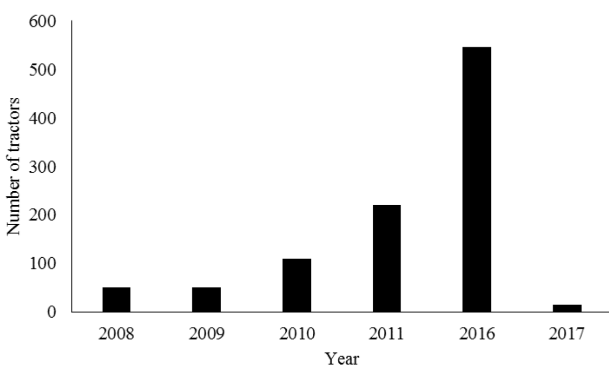

Fig. 3 Number of government-distributed tractors by year. Source: National Directorate of Agriculture and Silviculture (2017)

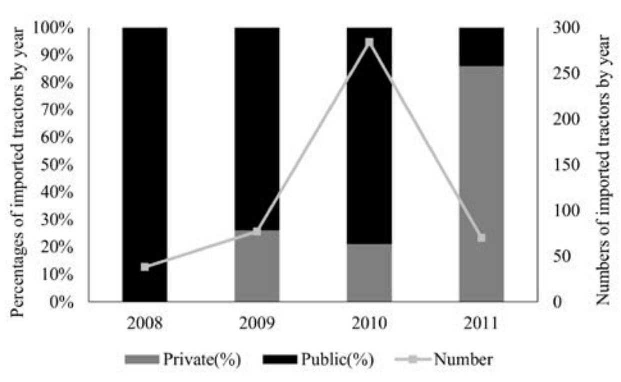

Fig. 4 Numbers and percentages of private and public sector imports of tractors (2008-2011). Source: World Bank (2012).

them profitable and enable them to provide more support services to farmers.

Lack of skilled human capital required for the operation and maintenance of agricultural machinery is one of the main factors constraining agricultural mechanization. This problem has resulted in early stagnation of available machinery and in the limited availability of machine parks in the country. The low level of mechanization, which is required to increase agricultural production and productivity, can be attributed to farmers' constraints in accessing credit for purchasing agricultural machinery. In northern Mozambique, animal traction technology has not been introduced because of fears and superstitions relating to witchcraft. Thus, a multidisciplinary study is necessary for achieving a successful outcome for the agricultural mechanization program.

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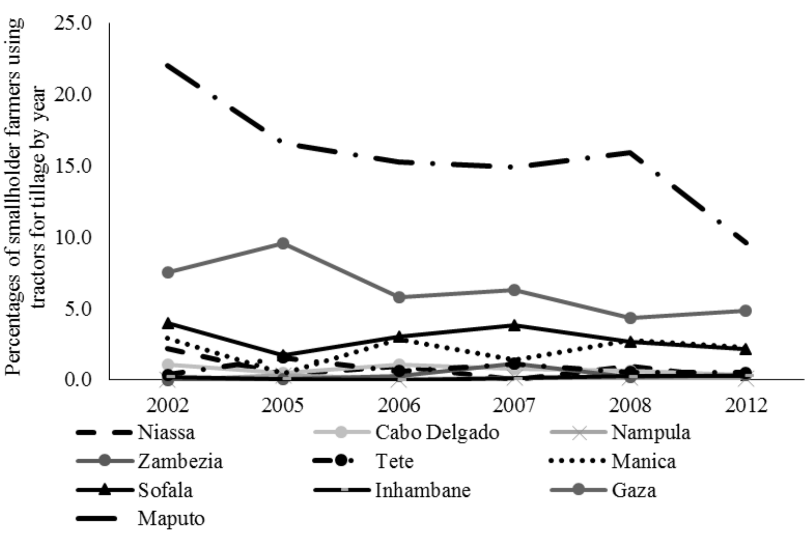

Fig. 5 Percentages of smallholder farmers using tractors for tillage in rural Mozambique.
Source: Cunguara *et al.* (2016)

A General Overview on Agricultural Mechanization in Zimbabwe

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Abstract

This paper gives a general overview on the current status and future prospects of agricultural mechanization in Zimbabwe. A survey of relevant literature and government policy documents was performed so as to determine the current position and future directions of agricultural mechanization. It was found that Zimbabwe is generally at the initial and intermediate stages of agricultural mechanization. This is a state whereby most farmers are moving from using hand tools to using animal draught power and hiring mechanical-powered tillage services. There is limited availability of information on the numbers of effective farm power machines in Zimbabwe. However, there is a strong political commitment to ensure the mechanization and modernization of Zimbabwean agriculture. Zimbabwe also has an important role to play in the attainment of the African Union vision to banish the hand hoe from tillage operations. Overall, there is strong market potential for farm power technologies. Appropriate mechanization strategies have to be adopted to suit the social and economic profile of Zimbabwe.

Introduction

Zimbabwe is located in southern Africa and is a land-locked country that shares a land border with Zambia, Botswana, Mozambique, and South Africa. Zimbabwe measures approximately 39.1 million hectares. The Food and Agriculture Organization of the United Nations (FAO, 2015) estimated that 4.1 million hectares of land in Zimbabwe (10.5% of the total land area) is under crop cultivation. It was further estimated by the FAO (2015) that 12.1 million hectares (31% of the total land area) are under permanent pastures that are used for livestock grazing. This gives a total of 16.2 million hectares (41.5% of the total land area) as agricultural land for both crop and livestock production while forest areas have declined to about 15 million hectares due to increased human activity. There is need for the application of fertilizers on 70% of Zimbabwe's soils as these are inherently of low fertility having been derived from granite parent material.

Maize (the staple food crop with a national demand of 1.8 million tonnes per year), wheat (annual national demand of 400 000 tonnes), sorghum, millet, potatoes (Irish and sweet), sugar beans, soya beans, ground nuts, tea, coffee, sugarcane, sunflower, tobacco (Zimbabwe's leading export commodity), cotton, citrus fruit, fresh vegetables, and barley are the major crops that are grown in Zimbabwe. Cereals (mainly maize and wheat) and sugar cane contribute approximately 65% of the food requirements for Zimbabweans (FAO, 2015). The bulk of the maize produced in Zimbabwe is from the smallholder farming sector. Zimbabwe at some point prior to the year 2000 used to be sufficient in maize production during years where there was adequate rainfall, but that does not mean that the surplus could feed the rest of Africa. Increasing climate variability and other economic factors have generally resulted in low total maize and other cereal grain production. The lack of adequate and appropriate agricultural mechanization is one of the economic factors affecting cereal grain production in Zimbabwe.

This paper aims to provide an overview on the status and prospects of agricultural mechanization in Zimbabwe. Agricultural mechanization is the application of tools (manual, animal or mechanical powered), implements, and machinery for agricultural production (Rijk, 1999). Farm power operations include land preparation, pressurized water delivery equipment for irrigation purposes, crop maintenance, harvesting, grinding and milling. Farm power technologies that are typically used in Zimbabwe and other African countries include the animal and tractor-drawn implements such as ploughs, planters, harrows, and sprayers; four-wheel tractors with two axles and either two-wheel drive or four-wheel drive; the upcoming single axle two-wheel tractors also known as power tillers that are being championed by the African Union Commission; crawler tractors such as bull dozers for land clearing; mechanized irrigation methods such as centre pivots and hose-reels and other pressurized irrigation systems; hand tools such as the axe for land clearing and the hoe for tillage or weeding; pumps that lift and pressurize irrigation water; motorized harvesting equipment such as combine harvesters; and crop processing machinery such as grinding mills for cereal grains. Mrema *et al.* (2018) indicate that four-wheel tractors and motorized grinding mills have been the most widely adopted advanced farm power technologies in Africa, and invariably this similarly holds true in Zimbabwe. Animal drawn implements are considered as intermediate farm power technologies while the primary/basic farm power technologies are the hand tools and manual threshers or grinders.

Farm Power Technologies Used in Zimbabwe

Agricultural mechanization is an enabler for increased agricultural production and enhanced agricultural productivity (Rijk, 1999; Thebe and Koza, 2012). The mechanization of Africa's agriculture, including that of Zimbabwe, is at its initial stages that involves the substitution of human muscle power and animal draught power with machine power and has remained in this state in the period 1985 - 2015 (Mrema *et al*., 2018). Through several Government initiatives in partnership with several countries including Iran, China, and Brazil, Zimbabwe has gradually replaced its four-wheel tractors particularly during the period 2005-2015. However, the number of four-wheel tractors has not increased at the same rate as the forest areas opened up for cultivation. The number of four-wheel tractors per thousand hectares of cultivated land has largely remained at around one as was between 1980 and 2000 with the total number of tractors being about 23,000 when factoring in replacements and those that became dysfunctional (Mrema *et al*., 2018). Accurate details on the numbers of tractors in Zimbabwe are not available as no census has being undertaken that is coupled with checking the technical functional status of the existing tractors. There is also limited availability of self-propelled combine harvesters that are used for medium to large-scale farm harvesting of maize, wheat, and soya beans. These have to be imported into the country by Government and the private sector. Both four-wheel and two-wheel tractors are imported into the country due to knowledge gaps for local manufacture. There is adequate local capacity to research and develop tractor-drawn implements such as ploughs and harrows. Equipment for water lifting and distribution is partially imported.

The increasing droughts and increasing climate variability has led to fluctuating planted areas that put a further strain on the largely used draught animals (oxen and donkeys). Climate has been among the factors hindering the successful adoption of mechanized agriculture. Resultantly, the use of agricultural machinery such as tractors has at times declined, and in several areas animal traction shifted back to hand hoeing due to, among other reasons, loss of draught animals to droughts, increased outbreaks of livestock diseases and deteriorating animal health service (Mrema *et al*., 2018). The cost of spare parts for animal drawn implements is generally high, leading to machine-powered technologies being considered as more sustainable agricultural mechanization. The availability and accessibility of fuel, lubricants, spare parts, mechanical repair artisans (Mrema *et al*., 2018), expert technical back-up services and fair means of trade are essentials for sustainable agricultural mechanization initiatives that involve mechanical (machine) power. Baudron *et al*. (2015) further state that sustainable agricultural mechanization interventions through the introduction of two-wheel tractors should target small-holding areas with stone-free arable soils where agriculture is at least partially oriented towards commercial production but constrained by labour shortages.

The hand hoe is the most popular tool used by farmers in Zimbabwe. It is used for various farming operations including tillage and weeding. Like in other parts of Africa, rural women have borne the brunt of using the hand hoe for tillage and measures are being sought to ease the burden on women. Other hand tools include the axe that is used in land clearing, and the sickle that is used in harvesting. Some small-holder farmers are comfortable using the sickle for wheat harvesting as they deem it to be more economical than hiring combine harvesters (Thebe and Koza, 2012). There are village-based blacksmiths who develop and repair hand tools but these are not easily accessible in the rural areas due to their limited total number (Ministry of Agriculture, 2006). The Institute of Agricultural Engineering leads in the training of blacksmiths (Ministry of Agriculture, 2006).

There is a wide range of mechanically-powered farm machinery that is available in Zimbabwe. These include land preparation equipment (front loaders, back hoes, excavators, graders, dozers, chisel ploughs, disc ploughs, disc harrows, rippers, pasturators), planters, fertilizer broadcasters/spreaders/applicators, sprayers, pasture harvesting equipment (balers, forage harvesters, rotary cutters, feed mixers), combine harvesters, and center pivots. The general economic life of tractors is set at 10,000 hours or ten years. This indicates that there is a heavy demand for replacement tractors in Zimbabwe when economic conditions permit. The integration of climate issues within the ministry responsible for agriculture will lead to greater appreciation on the synergy between climate, agricultural mechanization, and agricultural production. This could potentially increase the demand for weather recording equipment. For greater detail on the history and uptake of mechanization technologies in Zimbabwe, reference can be made to a 2010 Zimbabwe Institution of Engineers conference paper by T. Koza.

Organization Around Agricultural Mechanization

The Ministry of Lands, Agriculture, Water, Climate, and Rural Resettlement as it is presently called is the lead government institution that drives the agricultural mechanization agenda in Zimbabwe. The Minister responsible for agriculture at any time drives the formulation and implementation of agricultural mechanization policies. There is presently a Division for Mechanization within the Ministry of Lands, Agriculture, Water, Climate, and Rural Resettlement that is the lead government agency on agricultural mechanization issues. Research and training on agricultural mechanization on behalf of government is done mainly through the Institute of Agricultural Engineering. Further professional staff members for training and repairs are located at provincial offices of the Division for Mechanization. The District Development Fund (DDF) and the Agricultural and Rural Development Authority (ARDA) are the other governmental agencies involved in the provision of mechanization services at the lowest administrative levels (up to village level across the country or to those that surround the Agricultural and Rural Development Authority estates).

There are several other professional associations or organizations that are involved in agricultural mechanization research and development. These include the Zimbabwe Institution for Engineers that has membership under the agricultural engineering discipline; individual companies that manufacture, assemble, or distribute agricultural equipment; various universities (both state and private funded) with the University of Zimbabwe leading on agricultural engineering research and development including international organizations such as the Food and Agriculture Organization of the United Nations; the Engineering, Iron and Steel Association of Zimbabwe (EISAZ); and the Agricultural Dealers and Manufacturers Association of Zimbabwe.

The Engineering, Iron and Steel Association of Zimbabwe (EISAZ) is the longest serving employers' association (established in 1937) for the said sector with a primary focus on labour relations and technical standards compliance. Its membership is open to agricultural engineering companies among others. Major agricultural equipment manufacturing and distribution companies are members of the Engineering, Iron and Steel Association of Zimbabwe. This association is partially responsible for the development of financial and industrial capacity to enhance agricultural mechanization.

The Agricultural Dealers and Manufacturers Association of Zimbabwe aims to ensure that ethical trading conditions and standards of service are adhered to in the agricultural supply trade of Zimbabwe. Its members include manufacturers and suppliers of agricultural equipment including mechanized irrigation equipment such as center pivots. It organizes an annual Agrishow that showcases the full range of agricultural equipment that are available in the country and also highlights new agricultural practices. Local distributors of international leading brands exhibit the latest available equipment from the international market. The Government of Zimbabwe purchases the latest agricultural equipment that are suitable for the country's agricultural situation including combine harvesters that are showcased at the leading agricultural exhibitions.

Diao *et al*. (2016) stated that private sector supply chains easily form where demand for agricultural mechanization arises including the supply of two-wheel tractors where the private sector could procure or manufacture units and also provide after-sales services (Baudron *et al*., 2015). Franchises are also easily formed to bring in the latest agricultural machinery (Mrema *et al*., 2018) as well as provide acceptable levels of after-sales services so as to contribute to what is termed as sustainable agricultural mechanization (Mrema *et al*., 2018). Franchises of leading international farm machinery brands are well established in Zimbabwe. There are also several local companies that have the capacity to assemble international tractor brand components from knock-down assembly kits. Based on the demand for farm machinery, there are significant prospects for the establishment of further franchises and farm machinery assembly and distribution plants. Significant efforts into research and development are essential for the establishment of additional implement manufacturing plants and new tractor manufacturing plants.

Policy Issues on Agricultural Mechanization

The African Union Vision to Banish the Hand Hoe by 2025

The first aspiration of the African Union Commission Agenda 2063 is that of a prosperous Africa that is based on inclusive growth and sustainable development (African Union Commission, 2015). In the tenth article of the African Union Agenda 2063, one of the targets to meet this aspiration is detailed as having modern agriculture with increased production, productivity and value addition that contributes to economic prosperity and food security. This is reinforced by the thirteenth article that targets the use of science, technology, and innovation, and indigenous knowledge to find interventions leading to the banishment of the hand hoe by the year 2025 (**Fig. 1**) to make the agricultural sector more profitable and attractive to the continent's youth and women. The low development of mechanization in Africa has resulted in tortuous labour conditions for smallholder farmers and farm labourers that primarily affects African women and drives African youths away from rural agriculture (Baudron *et al*., 2015).

Fig. 1 African leaders receive a power tiller each to promote the use of two-wheel tractors in their home countries at the 2015 African Union Summit (Photo credit: African Union Commission)

Fig. 2 The former President of Zimbabwe and then-Chairperson of the African Union receives a power-tiller from the Chairperson of the African Union Commission in pursuit of the vision to banish the hand-hoe by 2025 (Photo credit: African Union Commission)

Agricultural mechanization is one of the proven methods to modernize and increase the production and productivity of agriculture. The hand hoe is considered as a torturous implement that should be antiquated in museums in the African Union Commission Agenda 2063 that should be replaced by two-wheel tractors with ploughing implements (**Fig. 2**). The arduous usability of the hand hoe is generally linked to tillage operations (Thebe and Koza, 2012). However, the hand hoe remains a versatile implement that is useful for light farm operations such as weeding and planting of row crops. The two-wheel tractor also faces some ergonomic challenges when used by women for tillage in heavy textured soils.

The Government of Zimbabwe has the opportunity to utilize its professional associations and networks on agricultural engineering and mechanization to achieve the realistic aspects of the African Union vision to reduce the use of hand hoes for tillage, particularly among women (**Fig. 3**). This could then be explored and implemented across the African continent. It is particularly relevant for the Government of Zimbabwe to steer such a process as the African Union Commission Agenda 2063 was published when the former president of Zimbabwe chaired the African Union.

Fig. 3 A two-wheel tractor two-row planter developed in Zimbabwe by a private company (Photo credit: Raymond Nazare, University of Zimbabwe)

The Policy on Agricultural Mechanization in Zimbabwe

The Zimbabwe Comprehensive Agricultural Policy Framework outlines policy statements and strategies for the development of the agricultural sector in Zimbabwe for the twenty year period from 2012 up to 2032 (Government of Zimbabwe, 2012). The vision of the Government of Zimbabwe is to attain food security and adequate nutrition through sustainable modern agriculture that significantly contributes to economic development through increased production and highly productive agriculture (Government of Zimbabwe, 2012). The challenge from Zimbabwe Comprehensive Agricultural Policy Framework is that it is highly fragmented and has a sector focus to all issues such that irrigation modernization and agricultural mechanization are not listed as policy statements to increase agricultural production and productivity. These are considered as standalone sector interventions. This is despite the rightful recognition in the National Agricultural Mechanization Strategy that agricultural mechanization is one of the inputs into agricultural production (Ministry of Agriculture, 2006). Post-production and post-harvest losses generally arise in cereal production due to inappropriate and inadequate mechanization in addition to reduced initial production capacity, partially due to the disaggregated policy approaches. This is a general challenge with a number of Zimbabwean Government policies that could better be addressed through a detailed policy analysis and integration process led by the Departments of Policy Formulation and Analysis, and Policy Implementation and Monitoring and Evaluation in the Office of the President and the Cabinet.

The Zimbabwe Comprehensive Agricultural Policy Framework lists three policy objectives for agricultural mechanization in Zimbabwe as increased access to mechanization services by farmers; improved farm structures and post-harvest facilities; and the conservation of soil and water resources. The National Agricultural Mechanization Strategy for the period 2007-2017 outlines measures to achieve these policy objectives (Ministry of Agriculture, 2006). Although the National Agricultural Mechanization Strategy views Zimbabwe as being fairly modernized in terms of agricultural mechanization compared to other African countries, there is skewed distribution of farm machinery with most of the communal farmers having no access to it. There is good recognition for the need for supporting infrastructure such as roads in areas where farm machinery is shared to make agricultural mechanization a success. However, the majority priority is taken as addressing lack of access to tillage services without taking an integrated approach such as livestock research for instances where animal draught power is used. For example, an FAO project in Tajikistan has improved pastures to support livestock production by enhancing the agricultural mechanization alongside the development of relevant infrastructure and improved agronomic practices (FAO, 2017). This shortcoming in Zimbabwe's mechanization strategy is partially addressed by the call for the formation of a National Committee on agricultural mechanization that brings different stakeholders to discuss the implementation of agricultural mechanization programmes.

Mrema *et al.* (2018) allude to the support that agricultural mechanization receives from policy makers and politicians in Africa. Agricultural mechanization is highly recognized as a development pathway in Zimbabwe. The President of the Republic of Zimbabwe, His Excellency Emmerson Mnangagwa, presented the keynote address at the Southern Africa Confederation of Agricultural Unions (SACAU) on 14 May 2018 in Victoria Falls and reiterated his Government's commitment to modernize and mechanize agriculture through multi-faceted strategies. He challenged the private sector to increase their role in agricultural financing by horizontal and vertical linkages to enhance agricultural productivity. The President has led in formulating strategic public-private partnerships to promote land and water utilization for increased food security in separate initiatives.

The role of the private sector in agricultural mechanization has been previously recognized and articulated by Clarke (2000). Similarly, in his State of the Nation Address on the 18th of September 2018 on the occasion of the opening the ninth Parliament of Zimbabwe, His Excellency Emmerson Mnangagwa reiterated the importance of the agricultural sector in Zimbabwe's economic revival. He highlighted that the modernization and mechanization of the agricultural sector would be achieved in an integrated manner through enhanced coordination and cooperation from the restructured lead Ministry (the Ministry of Lands, Agriculture, Water, Climate, and Rural Resettlement). The said Ministry brings together aspects of land and water development and management together with agriculture in light of a changing and increasingly variable climate. Climate is also particularly linked to agricultural mechanization in Zimbabwe as there is large of portion of farm power is provided by draught animals that are largely affected by droughts. Agricultural mechanization is, therefore, recognized at the highest level by the Government of Zimbabwe as a means of achieving highly productive land and water utilization as well as enhancing agro-industrialization. Mrema *et al.* (2018) stated that such an integrated and coordinated approach that ensures the availability of water alongside other inputs such as farm machinery, seeds, pesticides, and fertilizers has the potential to transform farming and increase agricultural productivity and production levels.

Conclusions

This paper has presented a general overview of the status of agricultural mechanization in Zimbabwe. There is a low level of agricultural mechanization among the majority of Zimbabwean farming areas except large-scale farming areas. There is generally a strong political will for the mechanization and modernization of Zimbabwean agriculture. Research capacity exists but further advancements are required to move Zimbabwean even further ahead. There is need for greater technical cooperation among related professionals for the success of agricultural mechanization interventions. Committees that bring together different stakeholders to discuss sustainable agricultural mechanization should be established or re-activated and maintained for integrated approaches to agricultural mechanization. Advancements should be made in linking climate with infrastructure development to support mechanization and livestock research.

There are panaceas in term of farm power technologies. Baudron *et al.* (2015) argued that measures that promote the use of two-wheel tractors (**Fig. 4**) were a sustainable route to mechanize African agriculture by also adopting conservation agriculture practices as two-wheel tractors usually have limited tractive power. There are some instances where the use of two-wheel tractors will not be appropriate. In Zimbabwe, it has been observed that some farmers are averse to high machinery operational costs such that they can revert back to the use of hand tools. The uptake of two-wheel of two-wheel tractors is also affected by ergonomic factors. The selection of appropriate mechanization interventions is essential as some farming fields generally have shorter lengths that affect the efficiency of large machines such as high power four-wheel tractors (Thebe and Koza, 2012) and this at times leads to operational challenges and financial losses of government-funded tillage services that rely on large machines (Baudron *et al.*, 2015). For large-scale farms it is imperative that sufficiently sized machines with adequate power and capacity to undertake all farm operations are available and utilized.

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Fig. 4 Picture of a disused 14.7 kW (20 HP) two-wheel tractor for Government tillage services in Zimbabwe that requires minor repair service. This picture shows that the uptake and utilization of two-wheel tractors is not high due to social and economic factors.

Break-Even Analysis for Hiring Decision of Agricultural Mechanization Services in Iraq

by

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Abstract

The hire of some agricultural machinery services to complete a specific process within the farm considers of an alternatives to own these machines. The main objective of this study is to estimate numbers of area units at break-even point. Mathematical logical methods were used to estimate the break-even point by using cross- section data in rice farms in Alnajaf province. Results indicated that the values of break-even point for different types of new agricultural field machinery were 67.4, 6.5, and 55.3 hectares for tractor and machinery of soil prepare, field sprayer, and combine harvester respectively, while the values of break-even point for different types of old agricultural field machinery were 29, 4.8, and 53.2 hectares for tractor, field sprayer, and combine harvester respectively. The study suggests that it is necessary and profitable for farmers in Alnajaf province to keep on the decision to hire agricultural machinery services.

Introduction

Rural people in Iraq depend heavily upon agriculture either as farmers, casual labourers, workers in agro-based industries, traders in agricultural produce or as hire service providers. One of the principal causes of poverty among small scale farmers, who plant less than three hectares of land, is the lack of mechanized farm power and importantly access to it. Lack of availability and access to farm power by smallholder farmers is a key factor that leads to a decline in production and consequently farm output (Organization of United Nations industrial development, 2008).

In the past, the Iraqi government imported the agricultural machinery from different countries due to their advantages in increasing the production and productivity, and distributed them through its warehouse network to farmers of cereal crops especially wheat, barley, and rice, due to their economic importance in achieving national food security and the acquisition these on a large area of cultivated land in Iraq (AL-agedy, 2006).

Most small scale farmers of cereal crops in Iraq, who plant less than three hectares of land, could not buy and use the agricultural machinery that have been imported by Iraqi government for many reasons and for some of them: the small size of the field does not allow the use of these machines with economic efficiency where the cost of operation of the machines is high, lack of spare parts and lack of suitability to the conditions of agricultural work in Iraq and also the use of the machines needed to other services as repairs and maintenance since these services cannot be provided by the farmers in Iraq (Al-tahan, 1991). Due to these reasons, the farmers of cereal crops and specially the rice farmers had to make a decision to hire different agricultural machinery and equipment from private sector to meet the requirements of agricultural production in addition to appropriate agricultural mechanization services due to the specific needs in each province of the Iraqi provinces. Current estimates indicate that 30 percent of farmers use their own equipment and 70 percent use a contractor for undertaking harvesting and seedbed preparation (Shukr, 2010).

For comparing between alternative contracts choices of use of the agricultural machinery services, two different situations have to be considered (Wander, 2004): (1) farmers already hire the needed machinery but seek whether owning is cheaper or not, and (2) farmers who need to decide about buying or hiring machinery services. Most small-scale farmers, who hire different agricultural machinery services in the southern central region of Iraq, are faced with a problem common to many farmers that is the amount of the hire cost. At present these costs make up 60% of total rice production cost (AL-tahan, 2011). The main purpose of this study is to estimate numbers of area units are needed to cover total fixed costs of machinery ownership.

Materials and Methods

This study was based on an empirical case study done in Alnajaf province that is located in the southern central region of Iraq. In this province, a lot of contractual bargains occur to hire agricultural mechanization services especially in scope of tractors, field sprayers, and rice combine harvesters that have already looked by small scale farmers. From farms of contracting machinery services in the province, a simple sample of 391 farms was randomly selected. The data were collected through a standardized questionnaire with open and closed questions applied on visits to mentioned farms during 2015 planting season. The theoretical framework of this research is based on analysis of break-even cost. A break-even cost analysis is a key part of any good business plan. In agricultural mechanization, the main purpose of break-even cost analysis is to determine the minimum area or hours that must be exceeded in order to make profit for ownership case.

Fig. 1 shows graphically break-even analysis between total revenues and total costs for purchasing the agricultural machinery (Wikipedia, 2016).

This figure indicates that at low levels of use, hiring a custom operator is less expensive, while for higher usage, the cost is lower if the machine is owned.

Mathematical logical methods were used to estimate the breakeven point. The break-even point is one of the simplest yet least used analytical tools in management. Estimate break-even point needs several basic pieces of information that include: total fixed costs, variable costs per unit, and average of hire price per unit (Mason, 1961). A determination of the breakeven point provides a useful guide to help farmers choose between machinery ownership and custom hiring. When the necessary cost data are available, the break-even point can be found from the following equation (Nuthall, 2010):

BEP units = total annual fixed costs ÷ (custom rate per hectare - variable costs per unit)

Results and Discussion

Analysis of Total Costs for Purchasing a Machine

Total costs of agricultural machines fall into two categories (Singh, 2006): Fixed (ownership) costs are incurred regardless of the number of acres or hours of use annually. Fixed costs include depreciation, interest, insurance, shelter or housing, and taxes and licenses fee (if any). Variable (operating) costs vary with the hours of machine use. These include fuel, lubricants, repair and maintenance, and labor.

Analysis of Total Fixed Costs (TFC) of study sample

Machinery reduces in value due to wear, age and obsolescence. The loss in value due to age and obsolescence is called depreciation. Machines depreciate each year regardless of the hours of use. Therefore, depreciation is considered a fixed cost. The change in a machine's value divided by the number of years of life of machine can be considered annual depreciation. There are various methods to determine a machine's value at the end of a specific period of time such as the

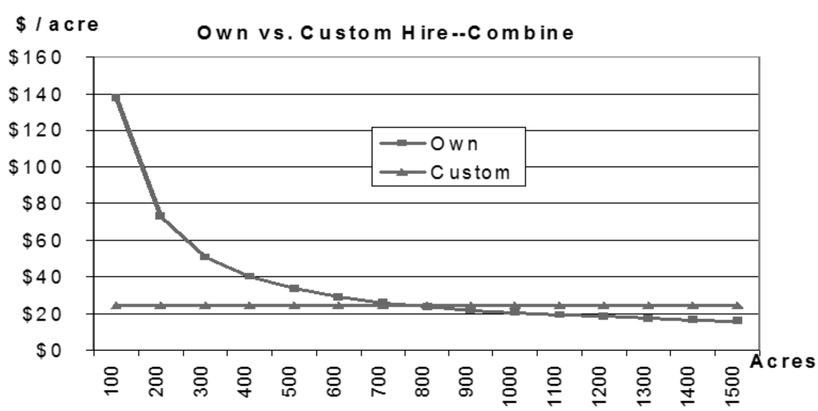

Fig. 1 Flowchart illustrates analysis of break-even as a theoretical framework

straight line or declining balance methods (Olson, 2004). However, if only the average annual depreciation is needed, it can be found from the following straight line depreciation equation:

Depreciation = (original cost - salvage value) ÷ years of useful age

The salvage value at various ages can be estimated as a percent of the new list price of a similar machine. A 10 percent of original cost of a machine was used in this research as a salvage value (Mason, 1961). In addition, the useful age was estimated as 15 years for a new machine and 5 years for an old or used machine (General organization, 2013).

A rate of interests on money spent on the purchase of machinery is another fixed cost. This may be a cash cost when farmers borrow money or an opportunity cost when they buy machinery with money that they have saved. Since interest cost does not vary with machine use, it is a fixed cost. A rate of 5 percent of the original value of machine was used in this research for estimating interest cost. This percentage of interest was associated with agricultural loans to purchase field machinery in Iraq during 2015 year.

Another ownership cost is the annual charge for insurance to cover damage to the machine from collision, fire, theft, hail, or wind, or for any liability coverage. The proper charge for insurance depends on the amount and type of coverage and insurance rates for a given location (Ronald, 2015). Most machinery cost studies assume a typical annual charge about 0.25 to 0.5 percent of the original value of machine. A rate of 0.25 percent of the machine's list price was used in this research as a ratio of insurance, because of a lot of respondents who own machinery could not do the insurance due to the lack of insurance divisions and services in Iraq.

Housing or shelter is also fixed cost. Most machinery cost estimates include an annual cost for housing the machine. Studies have found annual housing costs to be about 0.5 to 2 percent of the average value of the machine, so a value of one percent is often used to estimate machinery housing costs (Singh, 2006).

Finally, taxes and license fee as a part of total fixed costs for any machine (Snyder, 2011). These costs have not been taken in account in this study due to a lack of available data in study sample or there are no taxes and license costs imposed by Iraqi government on machinery ownership.

Table 1 shows categories of total fixed costs and their valves of different types of agricultural field machinery in Alnajaf province during 2015 season.

The results as can be seen in **Table 1**, the total fixed cost is more for new rice harvesting machines ($12,740) than for tractors and crop protection equipment. However, total fixed cost of machinery service is lowest for crop protection with old field sprayers ($38.80).

Table 1 Total Fixed Costs of different agricultural field machinery of study sample

Type of a machine	Tractor and machinery of soil preparation		Field sprayer		Combine harvester	
Items of fixed cost, $US/ yearly	New	Old	New	Old	New	Old
Depreciation	2,400	1,440	28.80	28.80	6,240	8,640
Interest	2,000	400	24	8	5,200	2,400
Insurance	100	20	1.20	0.40	260	120
Shelter	400	80	4.80	1.60	1,040	480
Total Fixed Cost	4,900	1,940	58.80	38.80	12,740	11,640

Source: prepared by researchers based on data of questionnaires

Analysis of Total Variable Costs (TVC) of study sample

Fuel costs depend on the hours of operation and the size of the machine or power unit. Fuel and lubrication include gasoline, diesel fuel, oil and other lubricants, and filters. These costs are minor for non-powered equipment but are important for self-powered machinery, such as tractors, sprayers, and harvesters (Gandonou, 2006). Farm records can be used to estimate average fuel use. Fuel cost per hour or hectare can be estimated by multiplying the estimated fuel use by the purchase price of the fuel. Questionnaires data depended in this research to estimate the consumed amount of fuel for each machine. Then multiply this amount by buying price per liter of fuel to get total fuel costs for different field machinery under study.

Lubricants and filters costs can be estimated by multiplying the fuel costs by 15 percent for self-powered machinery (General organization, 2013).

Repair and maintenance costs depend on hours of annual use and are difficult to predict because operators differ greatly in the levels of repair and maintenance performed. **Table 2** estimates repair costs based on annual use of different field machinery in the study region. The values of repair and maintenance costs in this Table were obtained from survey data.

Operator’s labour costs are also variable cost. To estimate the annual labour cost to run a machine, multiply the hourly average wage by the total hours required for the operation (Al-tahan, 2008). The hourly labour cost may be the hourly wages of hired help or an estimate of the operator's time based on the skill required to operate the machine and perform other tasks, such as management. The values of operators’ labour costs in the **Table 2** of different agricultural field machinery were obtained from survey data.

Table 2 shows categories of total variable costs and their valves of different types of agricultural field machinery in Alnajaf province during 2015 season.

The results as seen in **Table 2**, the total variable cost is higher for both new and old rice harvesting machines ($53.12, $41.68) than for soil preparation and crop protection equipment. While total variable cost of machinery service is lowest for crop protection with new field sprayers ($3.76).

Prices Rates of Custom Hiring of Different Field Machinery in Alnajaf Province

A hire is one of the sources of medium and long-term financing, which features enabling organizations to get out of the benefits of the asset without owning it. The hire or leasehold is a contract by which the rent payments on certain agreed-upon deadlines for the landlord of asset against the utilization of renting of the services provided by the landlord for a given length of time (Organization of ideas and business, 2016).

Total costs per unit of area or output should be compared when deciding between machine ownership and custom hiring. Custom charges are typically a fixed rate per unit, while ownership costs per unit will decline with increased use (Edwards, 2015). **Table 3** shows various prices of custom hire for different types of agricultural field machinery of study sample during 2015 planting season.

Table 3 indicates that rates of custom hire in Alnajaf province of each of tractor and machinery of soil preparation, field sprayer, and combine harvester services were $US 112, 12.80, 272 per hectare respectively. The high cost services hire of rice combine harvester belongs to the high investment value of this machinery.

Table 2 Total Variable Costs of different agricultural field machinery of study sample

Type of machine	Tractor and machinery of soil preparation		Field sprayer		Combine harvester	
Items of variable cost, $US/ hectare	New	Old	New	Old	New	Old
Fuel	27.2	32	1.6	2.4	11.2	12.8
Lubricants and oil	4.08	4.8	0.24	0.36	1.68	1.92
Repair and maintenance	1.6	1.92	0.32	0.48	12.8	22.4
Operators labour	6.4	6.4	1.6	1.6	16	16
Total Variable Cost	39.28	45.12	3.76	4.84	41.68	53.12

Source: prepared by researchers based on data of questionnaires

Table 3 Prices of custom hire for different agricultural field machinery of study sample

Field machinery	Custom rate of tractor services	Custom rate of sprayer services	Custom rate of harvester services
Custom rate: $US/ hectare	112	12.80	272

Source: prepared by researchers based on data of questionnaires

Table 4 Breakeven point value of different agricultural field machinery of study sample

Field Machinery	TFC ($US/ yearly)	TVC ($US/ hectare)	Custom Rate ($US/ hectare)	Break-Even Point/ hectares
New Tractor	4,900	39.28	112	29
Old Tractor	1,940	45.12	112	67.382
New Sprayer	58.80	3.76	12.80	6.5
Old Sprayer	38.80	4.84	12.80	4.875
New Harvester	12,740	41.68	272	55.325
Old Harvester	11,640	53.12	272	53.18

Source: calculated by researchers based on breakeven point equation

Calculation of Breakeven Point of Different Field Machinery of Study Sample

Table 4 shows a various values of breakeven point for different types of new and old agricultural field machinery of study sample during 2015 planting season.

The results in **Table 4** indicate that the values of break-even point for different types of new agricultural field machinery were 67.4, 6.5, and 55.3 hectares with respect to the tractor and soil preparation machinery, field sprayer, and combine harvester services respectively, which means if the specific machine would be used on less than 67.4, 6.5, and 55.3 hectares, it would be less costly to custom hire for the work, while above 67.4, 6.5, and 55.3 hectares, it would be less expensive to own a specific machine in the study region. Similarly, the values of break-even point for different types of old agricultural field machinery were 29, 4.8, and 53.2 hectares with respect to the tractor and soil preparation machinery, field sprayer, and combine harvester services respectively, which means if the specific machine would be used on less than 29, 4.8, and 53.2 hectares, it would be less costly to custom hire for the work, while above 29, 4.8, and 53.2 hectares, it would be less expensive to own a specific machine in study region.

Conclusions

The main objective of this study was to estimate the numbers of area units are needed to cover total fixed costs of machinery ownership. The theoretical framework was based on analysis of break-even. Break-even analysis was used to provide a useful guide to help farmers choose between machinery ownership and custom hiring by calculating break-even point units for different types of agricultural field machinery in the study region. Results pointed out that the size of area at the break-even point for both old and new tractors (29, 67 hectares) exceeds the size of area holding by small-scale farmers (3 hectares) in the study region by 45 hectares. Similarly, the size of the area when the break-even point for both old and new control sprayer (5, 6.5 hectares) exceeds the size of area holding by small-scale farmers in the study region by 2.75 hectares. Equally, the size of the area at the break-even point for both old and new harvester (53, 55 hectares) exceeds the size of area holding by small-scale farmers in the study region by 51 hectares.

In light of these results, the study suggests that it is necessary and profitable for small farmers in Al-najaf province to stay on the decision to hire and not to invest capital amount for purchasing of various agricultural machinery.

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Effective Purification of Concentrated Organic Wastewater from Agro-Industrial Enterprises, Problems and Methods of Solution

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Abstract

Theoretical analysis of the prospects for the application of physical and chemical methods of purification of large concentrated organic wastewater of industrial enterprises was conducted. On the example of the post-alcohol bard, it is shown that only the joint use of combined methods of cleaning such drains supercritical gasification and supercritical oxidation are capable of economically, energetically and environmentally efficient, compared with the biological methods to solve this problem.

Keywords: wastewater, supercritical gasification, post-alcohol bard.

Introduction

At present, the purification of concentrated liquid effluents from medium-sized and large-scale production enterprises is a big and difficult problem to solve. Such wastes are created by food industry enterprises (alcohol bard, beer grains, whey, etc.), agricultural enterprises (animal manure, bird droppings, plant waste), chemical, wood chemical, pulp and paper industries, water channels in the form of sewage sludge water, etc.

The peculiarity of utilized wastes is a large concentration of organic substances, where the chemical absorption of oxygen (COD) is from thousands to several tens and even hundreds of thousands of mg/L of COD.

Materials and Methods

Analysis of Methods for Solving the Problem

For such wastewater, biological purification methods that can be divided into anaerobic without the supply of air (oxidant) to the treated runoff and aerobic with air supply are widely known and widely used, where nitrification-denitrification processes are carried out and the dissolved organic compounds are converted to insoluble-sludge, which in turn are then disposed of by removal to landfills or by incineration.

The advantage of the actual anaerobic process of disposal of sewage from enterprises is a relatively small new growth of microbial biomass, the ability to work with the COD value at the level of tens of thousands of mg/L, and also the receipt of a commodity energy product - biogas. To the disadvantages of the anaerobic process of wastewater disposal is the impossibility of complete removal of organic contaminants at concentrations below 100 mg/L in COD, as well as long runoff times, calculated in weeks. The application of the anaerobic method, often called biogas method, can reduce the COD of the runoff by about an order of magnitude, which, however, does not allow the recycled runoff to be drained into natural water bodies.

The aerobic method, widely used in particular on municipal water canals, on the contrary, works well with a low COD of the purified medium (not higher than 2,000 mg / L), the processing time is much less than in the anaerobic method, and in turn allows to lower by 1 to 2 orders COD. A significant disadvantage of aerobic cleaning is high energy consumption for air aeration and problems associated with processing and utilization of large quantities of excess sludge.

Therefore, in the case of concentrated effluents with a high content of organic substances, where chemical oxygen uptake (COD) exceeds tens of thousands of mg/L, a combined treatment of wastewater is generally used. As the 1-st stage, anaerobic purification is used, in which the biogas produced, is used to power the equipment for wastewater treatment. After the 1-st stage of treatment, the runoff, which has a COD value of several thousand units, goes to the 2-stage of purification using the aerobic method to remove organic matter, where COD is reduced by approximately an order of magnitude and this water is either put into circulation for technical needs, or is discharged into the city sewer system, or is tertiary treated by membrane methods, for example, by ultrafiltration (Kudryashov, 2013).

Despite the principal possibilities of solving the problems of purification of concentrated effluents by a combination of biological and membrane technologies, as well as a well-developed technical side of this issue, practice shows the need for too much capital expenditure on treatment facilities and the need to allocate large areas for these facilities. In addition, the presence of open air tank mirrors that lead to unpleasant odors, the appearance of a large amount of sludge that needs to be disposed of, also indicates the need to search for alternative methods for treating sewage.

One of the most promising methods for purifying concentrated effluents, which appeared at the end of the last century, but which has not yet been widely adopted, is the known method of supercritical water oxidation (SCWO) (see, for example (Yesodharan, 2002; Bermejo and Cocero, 2006; Kritzer and Dinjus, 2001). If created in concentrated effluent water pressure above 22.12 MPa and heat the drain to temperatures above 374.15°C, the water that makes up the bulk of the runoff will transfer to the supercritical state, which is characterized by high solubility for organic substances in it and practically infinite ability to dissolve gases. Adding the oxidant in supercritical fluid at elevated temperatures resulted in virtually complete oxidation of organics to carbon dioxide and water, and heteroatoms - in corresponding harmless oxides.

At operating temperatures of more than 450°C and pressures above 24 MPa, the oxidation process usually takes less than a few minutes to complete. Due to the absence of gas emissions in the environment, the SCWO method is characterized by high environmental friendliness. The use of SCWO allows simultaneously solving the problem of utilization of sludge obtained by conventional biological treatment.

The use of SCWO for wastewater treatment and energy purposes has been the subject of many publications, including patents, since the mid-1980s (Modell, 1982). A large number of well-known companies have implemented the SCWO approbation for practical use (see, for example (Xu *et al*., 2012). As an oxidizer of organic substances, oxygen of air, pure oxygen, hydrogen peroxide, oxygen-containing gas, nitric acid, per chlorates, and ammonium nitrate can be used.

However, despite its undeniable advantages in terms of environmental cleanliness, the practical application of SCWO technology for concentrated effluents has certain drawbacks that do not allow sufficient use of the potential energy opportunities provided by organic impurities themselves. Let us explain this with a concrete Example 1.

Example 1. In fact, in accordance with the law of conservation of energy, even if the inevitable losses of thermal energy from the equipment to the environment are eliminated during SCWO, the maximum energy in the oxidation of impurities will be Q = qxm, where q is the specific heat of combustion of the impurity substance, m - the mass of this substance. At COD = 100,000 mg/L, the energy released during the oxidation of impurities in 1 m^3 of runoff is approximately Q ≈ 20 (MJ/kg) × 100 (kg) = 2,000 MJ. Specific energy consumption for evaporation of water (heat of vaporization) is 2.26 MJ/kg at atmospheric pressure. That is, its own energy during the oxidation of impurities is enough for evaporation of 2,000 MJ/2.26 (MJ/kg) = 0.88 m^3 of water. That is, we get that even in this ideal case, at the output of the system we will have a vapor-gas-water mixture temperature of about 100°C (the water will only partially be in the vapor state). If we try to apply the received thermal energy to generate mechanical energy, then the thermal machine will have an efficiency not higher than the efficiency of steam locomotive (according to the Carnot cycle, the efficiency is not more than (373 - 293) / 373 = 0.21, provided that the temperature of the refrigerator is 20 C). It is possible to produce no more than 2,000 (MJ) × 0.21 = 420 (MJ) of mechanical work, which, however, ideally would be sufficient for pumping 1 m^3 of liquid runoff under a supercritical pressure of 25 MPa through the SCWO reactor: 1 (m^3) × 25 (MPa) = 25 (MJ).

However, the main disadvantage of SCWO for the purification of concentrated effluents is the need to supply a large amount of oxidant to the reactor. The cheapest oxidizer is the oxygen of the air. Let the COD drain be 100,000 mg/L. Then, to purify 1 m^3 of drainage, ideally 100 kg of oxygen or 500 kg of air will be needed, i.e. approximately 400 m^3 of air/m^3 flow. When this amount of air is compressed to 25 MPa, its volume will decrease to 400 m^3/250 = 1.6 m^3, and 400 (m^3) × 0.1 (MPa) × ln (250) = 220 MJ will be produced under isothermal compression. In real conditions, with an excess of air of 50% and efficiency compressor 50% energy consumption for organic oxidation in 1 m^3 drain under supercritical conditions will be approximately 500 MJ. That is, the energy of the organic mass in the sink is not enough to obtain a self-sustaining process. At the same time, since the volume of gases (1.6 m^3) is significantly higher than the volume of the treated liquid (1 m^3), this causes problems in the operation of heat exchange equipment (air jams, reduced heat transfer efficiency, increased volume of pumped medium, etc.). It should also be noted that if there is a lack of oxidizer and incomplete oxidation of organic matter, the waste will contain organic remains. In this case, because of the remaining un-oxidized impurities remaining in the liquid, the problem of obtaining a clean runoff is not satisfactorily solved.

In particular, it is possible, and because of this fundamental drawback indicated in Example 1, the SCWO method has not yet found wide application in the industry for the purification of large-tonnage sewage.

Nevertheless, it is premature to refuse the use of SCWO for the disposal of concentrated organic waste water. The main advantages of SCWO, as well as of all physical and chemical methods in comparison with biological methods, are the high speed of the processes, several tens of minutes instead of several weeks, the absence of gas emissions, which allow creating relatively compact equipment that solves the problem of utilization of concentrated organic wastes with high environmental efficiency.

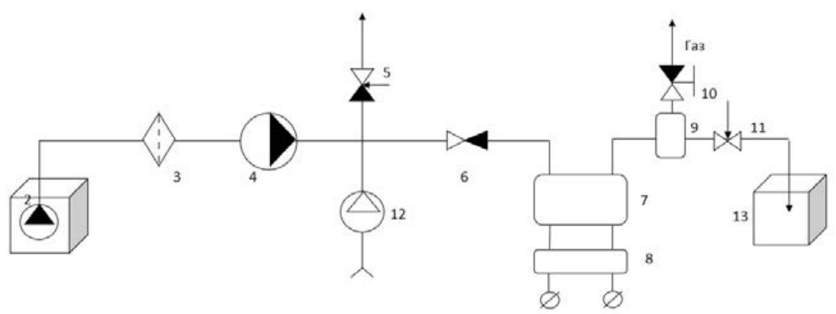

Fig. 1 Technological scheme of the experimental installation.
1 - Capacity for raw materials. 2 - The fecal pump. 3 - Filter with a cell up to 0.5 mm. 4 - High pressure pump. 5 - Safety valve. 6 - Check valve. 7 - Heat exchanger and SCWG+SCWO reactor. 8 - Electric heater. 9 - Gas separator. 10 - The valve. 11- Pressure regulator. 12 - Air compressor. 13 - Receiving capacity.

Let's consider the possibilities of increasing the energy efficiency of SCWO technology for the purification of concentrated organic waste water.

Investigation of Ways to Solve the Problem of Increasing the Efficiency of Physicochemical Methods for Purification of Concentrated Wastewater

To solve the problem of increasing the energy and economic efficiency of physicochemical methods for utilization of concentrated organic waste by reducing the energy costs for supplying the oxidizer to the reactor, there are two ways - either to find cheap organic oxidants, preferably liquid or solid for the convenience of their introduction into the reactor, or somehow way to lower the concentration of organic contaminants in the drain before the SCWO stage, without significantly increasing the flow volume.

The first way, naturally does not contradict the second, in this paper we will not consider it. Of the relatively cheap oxidants used in SCWO, pure oxygen (including liquid; Xu *et al.*, 2012), hydrogen peroxide, sodium and potassium perchlorates, ammonium nitrate, etc. can be mentioned. In the conditions of large-capacity drains, the economic feasibility of their application is not always justified.

The second, the most suitable way, in our opinion, is the preliminary use of another physicochemical technology - supercritical water gasification (SCWG) waste to prepare it for the SCWO, which allows the removal of a significant part of the organic matter from the runoff by transferring it to the gaseous phase.

Our previous experiments showed that SCWG as well as biogas technologies, although it allows us to remove a significant part of the organic matter in the form of gas from the treated liquid, but it is usually not possible to reduce the COD to values that are acceptable for release into natural reservoirs. It should be noted here that all experiments were carried out at temperatures below 600°C, when conventional grades of stainless steels can be used, and when chemical interaction of organic impurities with water can be neglected.

The purpose of this paper is to confirm experimentally the effectiveness of such a two-stage purification of concentrated wastewater.

The experiment was carried out on an installation and its schematic diagram is shown in **Fig. 1**. The alcoholic bard of the alcohol factory of the "Bryntsalov-A" was used as the liquid to be purified.

The processed liquid was continuously fed by a high-pressure pump (4) through a heat exchanger into a thermochemical reactor (7). In the SCWG mode, the gas was extracted from the liquid by means of a gravitational gas separator (9). The parameters of the liquid treated with SCWG are determined in the factory laboratory. Then this liquid was again passed through the same experimental setup, but an excess amount of oxidant (air) was added by the compressor (12) at the inlet of reactor (7) excess in comparison with stoichiometric amount of air, i.e. the SCWO regime was implemented. And already in the liquid treated at the SCWO, its parameters were again measured.

The productivity of the experimental setup was 20 L/h, the initial COD value in the bard is 85,000 mg/L, the initial content of ammonium ions is NH_4^+ = 350 mg/L. At the first stage of purification, when the SCWG technology was used, at 500 C the yield of combustible gases was 0.85-0.95 m^3/h (about 45 m^3/m^3 of bard). But if the original bard had a faint smell, then, after SCWG, the smell of the processed bard was exceptionally sharp.

The parameters of the liquid at the outlet after the SCWG reactor: COD = 8,700 mg/L, the content of ammonium ions NH_4^+ = 1,100 mg/L. It should be noted that an increase in the gasification temperature from 500°C to 600°C practically did not significantly affect both the gas yield and the odor and the results of instrumental measurements of COD and ammonium ion concentrations (see **Table 1**). A sharp increase in the concentrations of ammonium ions after SCWG should be explained by the decomposition of proteins contained in the original bard.

Experiments confirm that SCWG at reactor temperatures of up to 600°C does not in itself solve the purification of effluents to environmental standards (say, COD up to 30 mg/L), and an increase in operating temperatures above 600°C would lead to a significant rise in cost of plants due to the need the use of expensive heat-resistant materials.

Carrying out SCWO after SCWG using excess air in the same temperature range from 500 to 600°C completely eliminated the smells of the liquid, drastically reduced COD and ammonium ion concentrations to the values permissible for release into fishery ponds and almost completely solved the problem of cleaning highly concentrated wastewater.

Table 1 Typical change in the main characteristics of the bard as a wastewater after carrying out the SCWG and SCWG + SCWO

	COD, mg/L	NH_4^+, mg/L	Flammable gas output, m^3/m^3 of bard
Initial bard	85,000	350	-
SCWO	29	12	0
SCWG at 500°C	8.700	1.180	42
SCWG at 600°C	9.000	1.100	45
SCWG + SCWO	21.5	7.2	45

The water after a short settling time (5 minutes) was completely transparent.

It should be noted that the problem of post-cleaning of organic matter-free water to any condition from particles and salts can also be solved, for example, by well-known membrane methods, for example, ultrafiltration or reverse osmosis. In this case in the filtrate there would be valuable substances that can be used as additives that contribute to the improvement of the quality of organo-mineral fertilizers (Nugmanova 2017).

Results and Discussions

The technical and economic efficiency of the SCWG + SCWO scheme will be explained with a concrete Example 2. Let us choose the same raw data for sewage water as in the above Example 1.

Example 2. The initial runoff has a COD = 100,000 mgL. Let the potential thermal energy contained in the combustible gas be about 50% of the thermal energy of the dry mass of the organic impurity when the SCWG is carried out by the formation of simpler organic compounds in the processes of destruction. That is, in gases obtained from 1 m^3 of runoff (see Example 1) will contain 1,000 MJ of thermal energy. Suppose that after SCWG, 10% of the initial COD remains in the liquid, i.e. 200 MJ. When the residual organic impurity is carried out by SCWO, the temperature of the heating of the liquid in the reactor can be as follows: T = 200 (MJ) / 1 (ton) × 5 (MJ / (ton × grad)) = 40°C. This heating value is quite noticeable and with proper performance heat exchangers and good thermal insulation can provide a self-sustaining mode of operation of the installation. At the same time, when combusting the gas obtained at SCWG in the cogeneration mode (1,000 MJ), it is possible to obtain up to 400 MJ of electric energy and up to 600 MJ of thermal energy. This energy is certainly sufficient for pumping a cleaned drain, as well as on the implementation of a combination of SCWG and SCWO modes, in contrast to the pure SCWO regime. In this case we get both a good purification of the run-off from organic contaminants and additional energy in the combustible gas that can be used for commercial purposes.

Conclusions

Thus, the theoretical analysis and experimental studies of the combined SCWG + SCWO method of cleaning highly concentrated organic wastes, using the example of a post-alcohol bard, show convincingly the energy efficiency and environmental safety of this method. Compared with the widely known methods of biological purification of such wastewater, a significantly higher rate of physicochemical processes allows economically more efficient solution of the problems of cleaning large-scale wastes heavily polluted by organic wastewater and undoubtedly this technology should take a worthy place in solving environmental problems.

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Development and Evaluation of Self-propelled Puddler for Sandy-Loam Soils of West Bengal in India

by

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Abstract

Transplanting of paddy seedlings require puddling as a secondary tillage practice. In India, the machineries which are being used for puddling operation normally are animal drawn puddler, tractor's cage wheel and power tiller operated rotary tiller. A project was therefore undertaken to design, develop and evaluate the performance of self-propelled puddler for sandy-loam soil of West Bengal. A prototype of self-propelled puddler of 120 cm effective width was designed and developed at IIT Kharagpur. It comprised of two concentric cages and chain & sprocket for power transmission through gears. The inner cage as well as outer cage were powered and are fitted on a rotating shaft. The transmission system was developed for testing the performance of the puddler at single rotary speeds i.e.150 rpm. The performance evaluation of prototype puddler was done in the experimental farm of Agricultural and Food Engineering Department, IIT, Kharagpur. The average value of PI obtained was 59.6% for the first pass and 77.5% second pass. The average depth of puddle was found to be 10.7 cm for the developed self-propelled puddler which is at par with that of rotary tiller. Also, the specific energy expenditure was found to be 1,022.03 kJ/m^3 for the first pass and 1,168.03 kJ/m^3 for the second pass respectively.

Keywords: Transplanting, Seedlings, Self-Propelled, Puddling Index, and Specific Energy Expenditure

Introduction

India is predominantly an agricultural country. About, 60% of the total population of this country depends on agriculture. In India, rice is one of the important cereal crop and nearly grown in 24% of gross cropped area which contributes to 42% of total food grain of the country. It is grown in an area of about 42.30 Mha. Subsistence farming is practiced in some areas on small land holdings. Paddy cultivation is a drudgerious operation and mostly farm women are the main power source (Khadatkar *et al.*, 2018). The annual paddy production in the country is about 106.65 Mt in 2013-14. This is nearly about 22.4% of total world production (Anonymous, 2017). The relative lower yield may be attributed to many factors including poor production technology and lack of suitable implements. For seed bed preparation of rice, the quality of puddling is an important factor. Puddling reduced percolation losses through its effects on soil macro-porosity and saturated hydraulic conductivity and caused reduction in water consumption of rain-fed and irrigated rice. Many researchers studied the effect of type, size, shape, orientation and speed of operation of power tiller tynes under flooded soil conditions with a view to optimize the blade parameters under field as well as controlled soil-bin conditions.

Puddling is the secondary tillage practice for preparation of soil bed. Puddling may be defined as "mechanical manipulation of soil in presence of standing water in order to create a less pervious soil bed that prevents the loss of water through percolation and facilitate the transplanting of paddy seedling by making the soil bed softer".

Puddling is also defined as the process of tilling soil at high moisture content by a mechanical device which causes either shear or compression or both (Sharma and De Datta, 1985). During the puddling operation the soil is rigorously manipulated, soil structure is thoroughly disturbed and the air pore volume is drastically reduced (Awadhwal and Singh, 1985).

Puddling results in aggregate breakdown, destruction of macropores and formation of sub-surface dense layer, which together helps in transplanting, weed control and reducing deep percolation loss of water. Both breakdown of aggregates and formation of sub-surface dense layer are beneficial to rice production but harmful to the following arable crop. However, repeated puddling over time may lead to the development of plough pan, and cause reduction in yield of succeeding upland crops.

Transplanting of paddy is a critical operation. If it is done within recommended period, the yield increases. Prior to the transplanting, a paddy field has to be puddled, which requires a good amount of time as well as labour. In India, puddling is generally done by the local plough. However, a very small percentage of progressive farmers are using the animal drawn rotary puddler, tractor drawn rotary tiller or power operated rototiller for puddling operation. The use of animal drawn implement is very common in India due to the small land holding size and the fact that the cultivated area is normally not in a one compact block. Time requires to finish the job can be reduced if a power operated puddling device is used. Because of higher transmission efficiency, active machinery utilizes power of the prime mover more efficiently because, against passive machinery which utilizes least efficient output of power i.e. drawbar, where transmission efficiency is quiet less (less than 70%). Tractor's cage wheels are being used extensively for puddling which is poorly effective and causes excessive wear on the brakes. The rotary tiller tynes wear very fast and consume excess power. Also, the rotary tiller requires levelling operation as a secondary operation. Higher is the rotational speed of the rotor axle, higher is the power requirement.

Experiments were conducted to investigate influence of puddling implements on percolation rate and grain yield of rice in sandy loam soil of Kharagpur. Increase in grain yield was 40.3% over conventional method at 4 passes of power tiller (Amitava *et al.*, 2002). Three methods for quantitative measurement of puddling were suggested, viz. the analysis of water stable aggregates by wet sieving of puddled soil, measurement of specific weight and evaluation of moisture content of puddled soil. It was reported that the mean aggregate diameter which is the aggregate status of the water stable aggregate is the reasonable basis to judge the quality of puddle (Pandya, 1962). The puddling effect on mechanical characteristics of wet loam soil was also studied and the degree of puddle derived from shear yield strength ratio was found to be a suitable index for quantification of puddling and thixotropic effect on mechanical characteristics of soil (Awadhwal and Singh, 1992).

The performance of three different types of rotary tillage tynes, namely L-shaped (hoe type), C-shaped (slicer type) and pick type were tested at rotor speeds of 2.03, 3.56 and 5.08 m/s, respectively for a depth range of 5-15 cm in dry soil as well as in moist soil conditions. The results indicated that hoe type tynes operated at the lower rotor tip speeds and intermediate increments of cut showed the best performance with regard to power utilization and soil pulverization. It was also revealed that with double increment of cut, at same rotor speed, area covered was doubled but rotor horsepower increased only about 50% (Adams and Furlong, 1959).

A few selected bullock drawn puddlers were tested with plain blades of different sizes and it was noted that beyond two passes, increase in further number of passes had no significant effect on puddling quality (Sharma and Singh, 1984). Also, the effect of blade type on power requirement and puddling quality of a rotary tiller in wet clay soil was studied and the puddling quality was assessed in terms of bulk density and PI. The C type blade was found performing better than L and L-C type blade (Salokhe, 1993). The puddling effect on mechanical characteristics of wet loam soil was studied and the degree of puddle derived from shear yield strength ratio was found to be a suitable index for quantification of puddling and thixotropic effect on mechanical characteristics of soil (Awadhwal and Singh, 1992).

The performance of puddling implement and self-propelled rice transplanter was studied with crop establishment and grain yield of rice and it was reported that performance of rotary tiller with one pass was better than two passes of puddling harrow. However, the percentage of missing hills per unit area was found higher in the plots puddled with rotary tiller (Dhiman, 2002). The effect of soil and system parameters on the power requirement of rotary tillers was studied for four forward speeds of 2.59, 3.32, 4.67 and 5.97 km/h and six rotor speeds of 153, 170, 186, 203, 221, 237 rpm, and the final effect was seen on torque requirement characteristic of rotor shaft. It was observed that torque increased with increased depth of working and forward speed, and generally decreased with an increase in speed of rotation (Ghosh, 1967).

A mathematical model for mechanics of rotary puddler was developed and validate in the field for the work done by puddler on soil comprises of compressing the soil, shearing the soil, overcoming friction between soil metal surface, overcoming adhesion between soil and blade and accelerating and shifting the soil (Yadav, 1968). Also, a mathematical model for predicting the power requirement of a rotary tiller in saturated soil was developed and found for cutting the soil slices (0.34-0.59%), throwing the cut soil slice by centrifuging action (30.5-72.4%), overcoming soil metal friction (0.96-2.45%), overcoming soil-soil sliding friction (0.62-0.99%) and for idle power (23.1-64.6%) (Gupta and Vishvanathan, 1993).

A power operated puddler was developed by attaching a puddling unit in the power tiller and tested at the IIT, Kharagpur. It was noted that the rotating speed of inner cage wheel with 150 rpm and outer cage wheel with 20 rpm produced satisfactory results for puddling index (Maheswari, 2005).

The following equation was developed to evaluate the Pudding Index (Pandey, 1974).

$PI = (V_1 / V_2) \times 100$ ....(1)

Where,

V_1 = Volume of soil settle, m^3

V_2 = Total volume of the sample, m^3

Pudding Index was also evaluated on the basis of the principle of soil dispersion and is given as (Gupta, 1988).

$PI = (W_d / W_t) \times 100$ ....(2)

Where,

W_d = Dry weight of suspended particles, kg

W_t = Total weight of 200 ml sample, kg

The objective of this paper is to design and develop a proto-type self-propelled puddler for sandy-loam soil of West Bengal and to evaluate the performance of the developed puddler in the field.

Theoretical Considerations

This section deals with the criteria followed for the design and development of prototype unit a self-propelled puddler.

Design of Self-propelled Puddler

A proto-type self-propelled puddler having two concentric cages, both powered differently, was designed as per standard design procedure given below.

Design considerations

The design considerations which were kept in mind while designing the self-propelled puddler prototype unit were as follows:

1. The developed puddler should be capable of cutting the saturated soil and mixing it with standing water in order to create muddy soil bed.
2. The puddled soil bed should be sufficiently deep (10-12 cm) and having appropriate softness.
3. The designed puddler should be self-propelled.
4. Power requirement per unit volume of puddled soil must be low as far as possible.

Kinematics of active tillage tool

The working element of an active machine revolves around the axis mounted perpendicular to the direction of travel in addition to its linear forward movement. Due to combined rotary and translatory motion, it executes a complex motion. During operation, a point on rotary blade describes a trochoidal path known as cycloid. Different ratios of peripheral velocity to forward velocity give different trajectories of motion of the working element.

The volume of soil slice cut (V) can be approximated with acceptable accuracy using the formula:

$V = h \times l \times b, m^3$ ....(3)

Where,

h = Depth of operation, m

l = Tilling pitch, m = $\{(V_f / u) \times (2\pi R_r / Z)\}$ ....(4)

b = Width of soil slice cut, m

Power requirement of puddler

The power requirement (P) is the power required in cutting the soil, throwing the cut soil, overcoming soil metal friction and overcoming soil-soil sliding friction.

Power requirement in hp,

$P = (2\pi nT) / 60$ ....(5)

Total torque required for useful work,

$T = T_1 + T_2 + T_3 + T_4$ ....(6)

a) Torque required for cutting the soil slices in Nm, T_1

$T_1 = F_c \{R_r - (h / 3)\} = \sigma_s A_s \{R_r - (h / 3)\}$ ....(7)

b) Torque required for throwing the cut soil slices by centrifugal forces in Nm, T_2

$T_2 = F_{cf} \{R_r - (h / 3)\} = \{(m_s u^2) / R_r\} \{R_r - (h / 3)\}$ ....(8)

c) Torque required for overcoming soil metal friction in Nm, T_3

$T_3 = \mu_k \times m_s \times g \times R_r$ ....(9)

d) Torque required for overcoming soil-soil sliding friction in Nm, T_4

$T_4 = \tau \times A_{sc} \times \{R_r - (2 \times h / 3)\}$ ....(10)

Where,

F_c = Force required to cut the soil slice, N

F_{cf} = Centrifugal force required for throwing the cut soil slices, N

σ_s = Shear strength of saturated soil, N

A_s = Area of shear failure, $m^2 = b \times h$

m_s = Mass of soil slice cut, kg = $V \times \rho = (l \times h \times b) \times \rho$

μ_k = Coefficient of friction between soil-metal surface, N

g = Gravitational acceleration, m/s2

A_{sc} = Area of sliding of cut soil slice, $m^2 = h \times l$

τ = Shearing stress in pure shear, N/$m^2 = \{\eta \times (u / h)^{nps} + \tau_y\}$

τ_y = Yield stress in pure shear, N/m^2

η = Coefficient of viscosity, m/N-s

nps = Exponent

Design of puddler shaft

The shafts are generally subjected to combined twisting and bending moments. Various theories have been suggested to account for the elastic failure of the materials when they are subjected to various types of combined stress.

1. Maximum shear stress theory or Guest's theory: This is used for ductile

materials such as mild steel.

2. Maximum normal stress theory or Rankine's theory: This is used

for brittle materials such as cast iron.

The expression $\sqrt{(M^2 + T^2)}$ is known as equivalent twisting moment and is denoted by T_e,

$T_e = \sqrt{(M^2 + T^2)} = (\pi \times f_s \times d^3) / 16$ ....(11)

Puddler shaft is designed considering combined bending, torsion and axial loading. Equivalent moment (Me) considering bending, axial load and torsion is given by,

$M_e = (\pi d^3 \tau / 16) = \sqrt{\{(K_b M_b + \alpha P d / 8)^2 + (K_t M_t)^2\}}$ ....(12)

Where,

d = Diameter of shaft

M_b = Bending moment

M_t = Torsion / applied torque

P = Axial load

K_b = Combined shock and fatigue factor applied to M_b

K_t = Combined shock and fatigue factor applied to M_t

α = Column action factor

Design of cutting blades

The cutting blades act as a simply supported beam getting supports at two ends and having uniformly distributed loads. There are two uniformly distributed loads acting over a cutting blade. These are force required for cutting the soil slice and weight of soil slice over the blade. Both forces will not act simultaneously; hence design is done based on maximum force, out of these two forces. The blade will act as simply supported beam with uniformly distributed-load, maximum bending moment. The size of blade can be decided by using equation (13).

$(W \times l/8) = (\sigma_b \times b \times t^2 / 6)$ ....(13)

Where,

W = Force, N = w × l

1 = Length of blade (i.e. width of puddler), m

σ_b = Permissible stress, N/m^2

y = Distance of neutral axis from most outer fiber, m = t / 2

t = Thickness, m.

I = Moment of inertia, N-m^2 = (bt^3 / 12)

b = Width of blade, m.

Design of Suitable Power Transmission System for Puddler

Chain and sprocket transmission system is selected for the purpose of power transmission from rotary speed gear box to the puddler shaft, because chain and sprocket transmission have least losses due to slip. The chain and sprockets is designed following IS: 2403-1991.

The Chain is selected from standard roller chains based on design power and speed of smaller sprocket. Using pitch (p) of chain selected, Pitch circle diameter (Dp) of both sprockets is calculated using the expression,

$D_p = p \text{ cosec } (180 / T)$ ....(14)

Where, T = Number of teeth on sprocket

Pitch line velocity (minimum) is obtained from two sprockets and their speeds is calculated using the expression,

Pitch line velocity $= (\pi D N) / 60$ ....(15)

Where, N = Speed, rpm

Load on chain and Factor of safety (FOS) were calculated by,

Load (W) = (Rated power / Pitch line velocity) ....(16)

FOS = Breaking Load / Load on chain ....(17)

Chain length should remain almost constant for constant centre to centre spacing between sprockets. For mechanical power transmission, spur gears are used with the proper speed reduction at the outlet.

Materials and Methods

This section deals with the procedure and instrumentation involved in the design, development and testing of the power operated puddler. The power operated puddler prototype was designed using design as well as system and soil parameters. The design parameters selected were number of blades on powered cage, number of blades on dragged cage, width of puddler, diameter of outer cage and diameter of inner cage are 6, 8, 40 cm, 49 cm and 40 cm, respectively. Also, the system and soil parameters selected were rotary speed of operation, shear strength of saturated soil, dry bulk density of saturated soil, coefficient of friction between submerged soil and metal surface and forward speed of operation are 150 rpm, 800 N/m^2, 2,500 kg/m^3, 0.2 and 1.88 km/h, respectively.

Power Transmission System

A 5 hp gasoline engine with 2,400 rated rpm was used for power transmission through belt-pulley and chain-sprockets with proper speed reduction with spur gear. The power transmission system after the rotary speed gear reduction comprised two auxiliary stationary shafts (shaft 2 and shaft 3) having revolving sprockets over them and finally sprocket attached to puddler shaft (shaft 4).The speed reduction from engine to shaft was 1:16 in two stages for getting 150 rpm at inner cage. Whereas, the speed reduction from engine to clutch shaft was 1:120 in three stages for getting 20 rpm at outer cage. The line diagram of power transmission from engine to puddler shaft has been given in **Fig. 1**.

Power Requirement

Power requirement was calculated at all the selected rotary speeds but, it was found highest at 150 rpm, so it was used for further design pur-

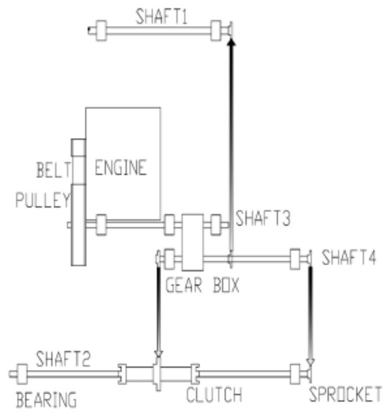

Fig. 1 Line diagram showing power transmission in prototype puddler unit

pose. Let, design torque be 1.5 times the theoretically calculated values. The design power and design torque were 1,638.6 kW and 146.78 Nm, respectively.

Design of Puddler Unit

The size of puddler shaft was finalized based on maximum design torque, respective bending moment due to weight of two cages, tension in chain between sprocket 5 and 6 and weight of sprocket 6 and chain as well as axial load. Taking permissible shear stress value as 50 MPa for mild steel, diameter of shaft at different sections was decided as 2.4 cm with stepping required for easy fitting and locking all accessories.

The newly designed proto-type puddler comprises of two concentric cages. Both the cages are powered. Two mild steel rods of 1.25 cm diameter and 125.7 cm length, and two 1.25 cm square bars of length 149.2 cm were taken and rounded on rod bender for making two rings of diameter 40 cm (for inner cage) and two rings of diameter 49 cm (for outer cage), respectively (**Fig. 2** (**a**) and (**b**)). The inner cage is moving at higher speed (150 rpm) and the outer cage at lower speed (20 rpm).

Mild steel flat was used for making blades of inner and outer cage. The size of blade for inner cage was 40 × 7 × 0.3 cm and that of outer cage was 46 × 2.5 × 0.5 cm. The locking collars and bushes were made using mild steel and brass, respectively. The float of puddler was made of mild steel flat of thickness 0.5 cm. The front portion was bent on a bending machine to obtain the desired shape.

A dog clutch system was developed for turning the machine and was provided on rear shaft. The clutch was made from mild steel rod of 7 cm diameter by turning it into a desired shape on lathe. The inner and outer diameter of fabricated clutch was 4 cm and 5.5 cm, respectively. The dog clutch consists of four groves equally spaced with 1.1 cm deep.

Assembling of Self-Propelled Puddler

The blades of both inner and outer cage were welded on the rings. Eight mild steel rods (spikes) of size 1.25 cm diameter and 16.25 cm were cut and welded with the collars (four spikes on each collar) for fixing the inner cage on puddler shaft. For outer cage, spikes were brazed on the brass bushes. Then the rings and the spikes were welded together. In this manner three puddler units were assembled and the three units were arranged in a triangular manner. One unit was mounted on front shaft and the other two units were on rear shaft. The three units were fixed on the frame with bearing. The engine was placed in between the front and rear shaft for stability. The units were arranged in such a way that effective width of puddling increases to 1.2 m. The complete system was shown in the **Fig. 3** and **4**.

A self-propelled puddler prototype unit was designed and developed successfully (**Fig. 5**) at Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur. The performance of puddler was evaluated at 150 rpm rotary speeds and two passes. In order to evaluate the performance of newly designed puddler

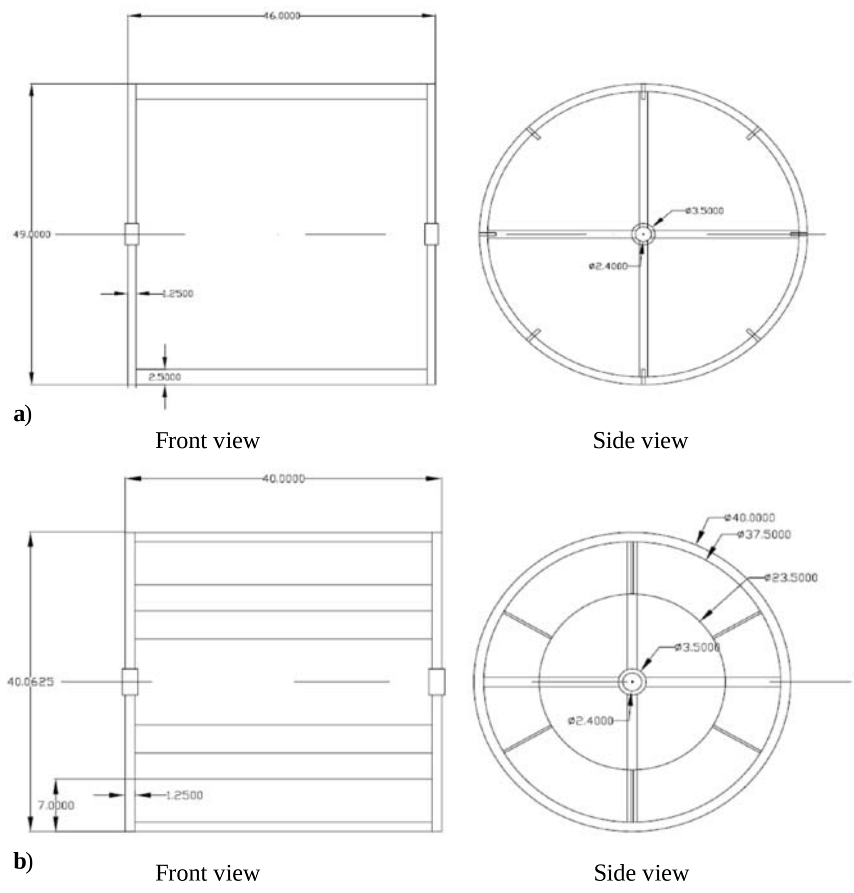

Fig. 2 **a**) Outer cage of self-propelled puddler; **b**) inner cage of self-propelled puddler (all dimensions in cm)

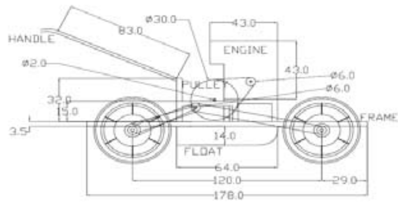

Fig. 3 Side view of developed self-propelled puddler (all dimensions in cm)

prototype, field experiments were conducted in the experimental farm of the department.

Testing of Developed Puddler

The developed puddler was evaluated by using RNAM test Codes and procedures for rotary tillers (1995). A piece of (10 × 20) m^2 land was chosen in the experimental farm of Agricultural and Food Engineering Department. The field was ploughed once with a cultivator. The plot was filled with water 24 hr before conducting experiment. The level of standing water during the experiment was maintained at 5 cm. The rotary speed of inner cage and engine were measured in the field using a tachometer and was maintained during entire treatment by fixing throttle position. The forward speed was measured by manually measuring time to take a fixed distance using a stop watch.

During the experiment, fuel consumption was recorded. The fuel consumed during turning was excluded and then specific energy expenditure (SEE) was calculated. The energy expenditure (EE) for puddling a given area at a given depth of operation can be measured by measuring fuel consumption.

To evaluate the performance of developed puddler following research plan was adopted (**Table 1**).

Depth of puddle was measured after 24 hrs of puddling using probe of 2.54 cm diameter and 100 cm length. The probe was inserted into puddle and pressed gently up to the force required was increased. The depth of puddle was also measured by pushing plastic scale gently in puddle after 24 hrs of puddling, until the force required for penetration was increased. The degree of puddling is then expressed by calculating the puddling index.

The SEE is the energy expenditure for pudding unit volume of soil. It provides a common platform for comparing cost of operation with different type of puddlers. The EE for puddling a given area at a given depth of operation can be measured by measuring fuel consumption and the volume of soil puddle can be obtained by measuring depth of operation.

EE (kJ) = Fuel consumption (ml) × Calorific value of fuel (kJ / ml) ....(18)

SEE (kJ/m³) = EE (kJ) / Volume of soil puddled (m³) ....(19)

The performance of developed self-propelled puddler was evaluated in terms of depth of puddle, PI and SEE at 150 rpm and two passes. The puddled soil samples are collected soon after the puddling operation was done. The sample was then allowed to settle down for 48 hours. When the soil particles in suspension settle down completely, the volume of settled soil is measured.

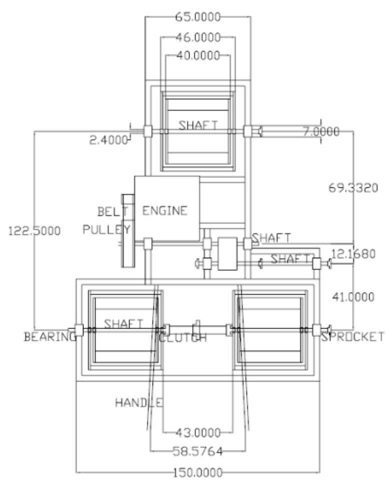

Fig. 4 Top view of developed self-propelled puddler (all dimensions in cm)

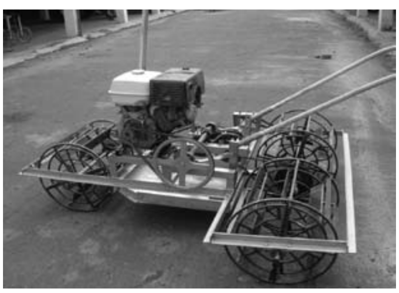

Fig. 5 Developed self-propelled puddler prototype unit

Results and Discussion

The procedure followed in evaluation of performance of the puddler has been described below.

Performance Evaluation of Developed Self-Propelled Puddler

The performance evaluation of puddler involves change in soil condition as well as energy expenditure. It is desirable to have minimum energy expenditure for getting desired soil manipulation. Three samples were taken for measuring PI and average was calculated. The average value of PI obtained was 59.6% for the first pass and 77.5% second pass. The value of depth of puddle varies from 9-12 cm. The average depth of puddle was found to be 10.7 cm for the developed self-propelled puddler

Table 1 Variables for performance evaluation

Particulars	Levels
Independent variables	
Soil type and condition	1 (Sandy clay loam, flooded with water)
Pre-treatment given prior to puddling	1 (Ploughing with cultivator followed by flooding)
Depth of ponded water	1 (5 cm)
Forward speed	1 (1.88 km/h)
Implement configuration	1 (Developed self-propelled puddler)
Depth of operation	1 (8 cm)
Rotary speed	1 (150 rpm)
Number of passes	2 (1st pass and 2nd pass)
Dependent variables	
Puddling Index	PI (%)
Specific Energy Expenditure	SEE (kJ/m³)

which is at par with that of rotary tiller.

The SEE was thus calculated and the values were 1,022.03 kJ/m^3 for the first pass and 1,168.03 kJ/m^3 for the second pass. With increased number of passes for the same rotary speed, the specific energy increased. The specific energy expenditure was increased with increased number of passes because here the entire soil was puddled as much times as the number of passes, but as the number of pass increased the specific energy expenditure for that pass only was less than preceding pass, because in each new pass the working tool handled comparatively more disturbed soil.

One operation with cultivator in dry condition and one operation with developed puddler in wet condition were done for puddling. Results reported that on an average puddling index in plot prepared by puddler was more than the plot puddled by the traditional practice, which is a desirable feature for better puddle. The field capacity of puddler combination was 0.25 ha/h compared to the 0.167 ha/h of the traditional method. These results further indicated that there was an average 34% saving in time over the traditional practice. The cost of operation in both the practices was also calculated. There was an average 16% saving in cost of operation.

Conclusions

A prototype self-propelled puddler of 40 cm width was designed and developed at Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur. It comprised two concentric cages and chain & sprocket for power transmission through gears. The inner cage and outer cage was powered. Both cages were fitted on a developed shaft. The transmission system was developed for testing the performance of the puddler at single rotary speeds i.e. 150 rpm. The effective width was 1.2 m that is three times as compared to the rotary tiller so that more area was covered in less time.

For measuring the PI, three samples were taken for each pass and the average PI thus obtained was 59.6% for the first pass and 77.5% for the second pass. The average depth of puddle was 10.7 cm with the developed puddler. The fuel consumed was also measured. The value of SEE obtained was 1,022.03 kJ/m^3 for the first pass and 1,168.03 kJ/m^3 for the second pass. With increased number of passes, the PI as well as the specific energy expenditure increased. Puddling reduces percolation of water, controls weeds, levels soil surface, and facilitates good mixing of fertilizer and ease transplanting.

Acknowledgements

A prototype self-propelled puddler was designed and developed at Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur as a part of M.Tech Project. The author is thankful to the Dean and Head (AGFE), Indian Institute of Technology, Kharagpur for providing facilities to complete this work.

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Seedling Beet Application in Sugar Beet Agriculture

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Abstract

Early sowing is an important factor in sugar beet agriculture in order to increase yield and quality. Sugar beet seedlings are grown in greenhouse and planted as early as the permission of weather conditions increase yield and quality. For this purpose, 5 ha seedling and normal beet were grown for both areas in Ararat province; yield, quality parameters and economical evaluation were done. 0.5 ha in each 10 plots were planted and sowed for both methods in the test and the results were compared with t-test. As a result of the test, 11.26 t ha^{-1} yield, 0.46°S sugar content, 0.57°S refined sugar content and 2.02 t ha^{-1} refined sugar yield increase were obtained in seedling method compared with conventional method. Because of high application cost of seedling method, 764.48 \$ ha^{-1} less net income was obtained, though yield and quality increase. This amount corresponds to approximately 6.95 t beets. 18.21 t ha^{-1} yields are required to taken in seedling method in order to obtain equivalent income with the conventional method. However, if supplying the seedlings outside of the farm instead of growing in the farm, seedling unit cost can be reduced and it may be possible to apply of this method, which provides increased production, in sugar beet production area.

Keywords: Sugar beet; seedling; transplanter; yield and quality

Introduction

Most of the food produced in the world is obtained from about 150 cultivated species. Sugar (sucrose) is produced only from sugar cane and sugar beet. Cane sugar is produced extensively in the tropics regions for centuries and meets 80% of world sugar needs'. However, sugar beet is a newer plant seen in temperate regions in the 19th century and become widespread in the 20th century (Draycott, 2006). Produced 173 million tons sugar (sucrose) as of the 2014/15 marketing year in the world about of 79% is produced from the cane, 21% from sugar beet. There are 111 countries are producing crystal sugar in the world. 69% of these countries are produced sugar from sugar cane, 35% are sugar beet and 7% are both (Agrinews, 2016).

The length of the growing period is one of the important factor effects on yield and quality in sugar beet farming. Longer growing season's length increases yield. Therefore, early sowing as far as possible in the spring is the most important factor to get high yield (Hubbell, 1991; Theurer and Doney, 1980; Elverenli and İnan, 2002). Sowing sugar beet seeds to paper pot and planted 4-6 leaves stage of seedling to field normal sowing time after germination in the greenhouse, allows the extending the growth period of beet without any adverse effects on plant growth (Theurer and Doney, 1980). Beet seedlings enlarge the leaf area quickly and grow faster than the beets sowing with conventional method. The growth difference in favor of seedling remains the same during the growing duration between seedlings and conventional (Scott and Bremner, 1966).

Seedling planting practices in sugar beet farming has some advantages such as; high yield due to longer growing period, precise control of the plant in seedling stage, homogenous plant distribution, allow use of wider range of herbicides, being resistant to frost, nematodes, diseases and pests. However, disadvantages such as the height application cost of the method and also needs additional labor should not be ignored (Dimsey, R., 2009; Heath and Cleal, 1992; Scholz and Boe, 1984). The most common seedlings methods applied region is Japanese island of Hokkaido which has short growing period and relatively small sowing areas (Fletcher and Prince, 1989).

In many studies about seedling method, it is reported that increases the beet yield but doesn't cause a significant difference in the sugar content (Scott and Bremner, 1966; Eto *et al.*, 1964; Scholz and Boe 1984). Some researchers have suggested that increases either beet yield or sugar content (Brummer, 1975; Dillon *et al*., 1972; Dimsey R 2009). Seedling method was reported to increase beet yield about 10% the trials in England (Heath and Cleal, 1992).

Fig. 1 Closed shape of paper pot

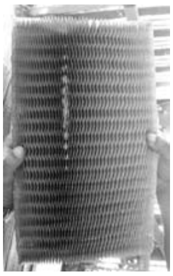

Fig. 2 Opened image of paper pot in which seedlings beet grown

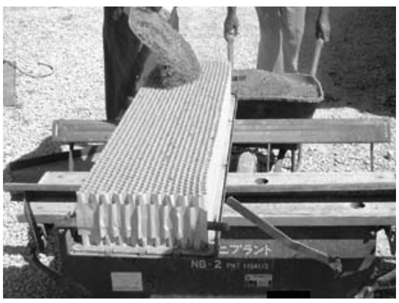

Fig. 3 Soil filling in paper pot

Fig. 4 Sowing plate

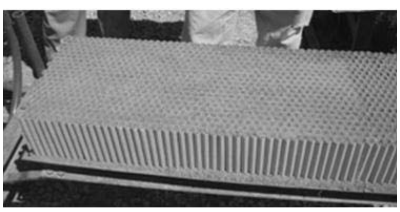

Fig. 5 Sowed paper pot

In this research, it was aimed to grow sugar beet with seedling method and compare with the conventional method applied in Ararat province Baloluk and Bölükbaşı regions in Turkey conditions as in Japan which has short growth period and small sowing area.

Material and Method

Specifications of Trial Location

Trials were carried out in Ararat province, Baloluk and Bölükbaşı region in Turkey between 2010 and 2013. Ararat has a volcanic structure, less precipitation, mountains and plains is bare due to the very low temperature. 20% of the land is pasture and grassland 80% of land is not conducive to the cultivation. It shows land climate characteristics. Winters are very cold and summers are hot. Springs and autumns take too short. 115-125 days of the year are covered with snow. It takes less rain and more snow. The average annual precipitation is 328-545 mm (Ararat, 2016).

Preparation of Soil and Paper Pot

All of the patents used paper pot belongs to the Nitten Company in Japan and is produced by the company and offered for sale. Cylindrically shaped one tube is 1.4 cm diameter and 13 cm length. 1,400 tube is termed as a unit and the unit paper pot is folded case before using (**Fig. 1**). Paper pot opens like an accordion while using (**Fig. 2**).

After stretched one unit paper pot become 30 × 120 cm size and filled with specially prepared seedling soil (**Fig. 3**). Seedlings soil is prepared by mixing sieved normal field soil, 15% sheep manure and 20% sand. While soil preparing 0.8 kg chemical fertilizer was applied to 50 kg soil. It was used 16 g N, 150 g P_2O_5, 8 g K_2O ve 42 g MgO chemical fertilizer mixture for a unit (Scholz and Boe, 1984).

Optimum moisture content of the soil is between 13-16%, must not contain stones and clods. Necessary amount of soil for filling one unit together with the losses is about 50 kg. After the tube is filled with the soil cover soil is added on the paper pots. Cover soil is almost the same as the seedling soil. About 1.7 kg cover soil is needed for one unit and Rhizorex (0.75 g active substance) which the active ingredient toruchlophosmethyl or Tachigaren (0.6 g of active ingredient) which the active ingredients Tagiant hymexazol is added against fungal diseases such as Rhizoctonia, Pythium and Aphanomyces. Filling soil to paper pot is made by hand using shovel. But the paper pot is shaken up and down constantly for a complete settlement of soil to the tube.

Seed Sowing and Seedling Planting

The paper pot is placed on planting plate after opening the tube, each hole of paper pot which has 1,400 holes are placed on the eyes of sowing plate and sowing is made. There is 700 holes on the sowing plate and the hole dimension is 5.5 or 6.0 mm (**Fig. 4**). Sowing plate is filled with seed and then adjusted to be aligned as each seed hole over the tube and the plate is pulled. So planting is completed (**Fig. 5**). This process is repeated two times and sowing of the one unit paper pot is completed. The surface of seed is covered with the cover soil after sowing seeds and surface is levelled.

Approximately 20% more seedlings were grown for 0.1 ha for being possible plant deficiencies in sowing to the paper pot and also considering the lack of seedlings that may arise from germination and other losses. For this reason, 82 units ha^{-1} seedlings were used in planting seedlings (**Fig. 6**). Paper pots which were placed to greenhouse immediately after sowing, it is covered with a thin polyethylene sheet on the paper pots in order not to lose the moisture. After the third day, about 10 liters water was given for each unit. The water temperature is required to be 20°C. The temperature inside the greenhouse should be 25°C during the day, should not fall under the 5°C at night (Scholz and Boe, 1984). Germination began from the 7th day after sowing the seeds under normal conditions and 94-95% germination rate was achieved on 14th day. It was sprayed by 30 g active ingredient of 1 liter Tachigaren (Hymexazol A) per unit when germination begins, one more spraying was applied at the same dose when germination completed. Seedlings are being 4-6 leaves cases which is the size of planted approximately 30-40 days.

Field Sowing and Planting

Field, representing the Ararat were selected from the fields which were plain, medium-heavy textured, quick weathering, near the road and easily watering places. Field was generally plowed by moldboard plough in autumn, in case of unsuitable weather conditions plowed in the spring. Seedbed and planting preparation was made by rotary tiller and crumbler in the spring. Whole of 200 kg ha^{-1} P_2O_5, 100 kg ha^{-1} K_2O fertilizer and half of the 200 kg ha^{-1} N were applied to the trial plots before sowing and planting and the rest of the fertilizer were applied before hoeing in seedling method and before last hoeing in conventional method. Naked Coyote variety sugar beet seed were used in both methods. Greenhouse sowing was started 18 March in order to prevent delays that may be caused by climate and continued until 7 April. Field sowing and planting started at the same time on 23 April, in case of weather conditions permit continued until 20 May at the 4-6 leaves stage of seedlings. Thus, seedlings damage were prevented by early sowing the seeds to paper pots and grown seedling excessively in the event of planting delays.

Trial Plan and Evaluation

Half of trial field (0.5 ha) was sowed by conventional method (control) the other half (0.5 ha) was planted seedling method. Transplanter was adjusted as the distance between rows was 55 cm and seed space in row was 20 cm so as to be adjusted about 90,000 plants per ha. Normal sowing was carried out as 45 cm row width, 8 cm seed spacing and singled 20-24 cm seed distance in row so that was 90,000 plant per ha to make equal treatment with seedling method. In total, 0.5 ha normal sowing and 0.5 ha of seedling planting were made in 10 different fields of two villages. After planting, life water was given to the seedlings and emergence water to the normal sown seeds. Total 4-6 irrigation performed during the years when the experiments carried out and treatments were applied equally to both methods based on normal conditions. Harvest was made on 1 October. 6×10 m^2 area in each plot from 10 different regions were harvested separately in order to make yield and quality analysis.

Fig. 6 Sugar beet seedling

Fig. 7 General view of transplanter and planting

Beets were washed, weighed and samples taken by milling for laboratory analysis after harvest. Dry matter (°S), sugar content (polar sugar PE) measurement performed from the examples (Şiray, 1976), determined the amount of sodium (Na), potassium (K) and α-N (Kavas and Leblebici, 2004). Based on these values the presence of refined sugar content and refined sugar yield was calculated (Reinefeld *et al.*, 1974). The research results were subjected to t-testing according to trial plan (Düzgüneş *et al.*, 1987).

Transplanter

Transplanters which were two-row BST and three-row BSR Seedling Select brand manufactured by Japanese Circle Tekko Co. Ltd. was used (**Fig. 7**). It was 0.7-0.8 ha planting per day performed with two-row machine and 1.2-1.5 ha planting performed with three-row machine.

Results

Climate

Sugar beets are long-day crops; therefore they are generally sown as early in spring as possible. Important environmental variables that determine the beginning of sugar beet growing processes are temperature, precipitation and soil moisture. The sowing time was influenced by the cultivation technology, the pre-sowing applications tended to delay the sowing date. The beginning of sowing also depends on the weather conditions. Due to the agroclimatic conditions, sugar beet sowing can start earlier or can be delayed: precipitation which often occurs during pre-sowing soil tillage replenishes soil moisture reserves and can cause a delay. During the period 2010-2013, the average amount of precipitation that fell from the March to June varied 50.9, 71.2, 70.7, 45.1 mm. The highest temperature in the same mounts was realized as 21.5, 27.2, 32.7, 39.8°C and the lowest temperature was -39.6, -25.6, -9.0, -3.0°C respectively. In this conditions; the sowing and planting was completed until the end of May each year in the trial.

Yield and Quality

The difference between the yield and other quality values were statistically significant according to the results obtained from conventional and seedlings methods made research in the fields of Baloluk and Bölükbaşı village in Ararat province (**Table 1**). An average of 114,800 seedlings ha^{-1} was prepared in seedling method and 90,000 seedling units were planted with a loss of about 21.60%. The loss was realized as 24.43% between planting and harvest and 68,010 beets ha^{-1} were obtained at harvest (**Table 2**). Root yield was 47.34 t ha^{-1}, sugar content 18.22%, refined sugar content 15.88% and refined sugar yield was 7.54 t ha^{-1} in seedling method. Root yield was 36.08 t ha^{-1}, sugar content 17.76%, refined sugar content 15.30% and refined sugar yield was 5.52 t ha^{-1} in conventional sowing respectively (**Table 1**).

Each one week sowing delay causes 4-7 t ha^{-1} sugar loss in sugar beet cultivation (Scott *et al.*, 1973; Jaggard *et al.*, 1983; Çakmakçı and Oral 2002; Petkeviciene 2009). In this research, although there were 38% more plants per hectare in conventional method, the 25-30 days longer growth period have led to higher yield in seedling method. The difference between the conventional and seedling methods was 11.26 t ha^{-1} in terms of root yield, 0.46°S of sugar content, 0.57°S of refined sugar content and 2.02 t ha^{-1} of refined sugar yield (**Table 1**). The differences in root yield and refined sugar content values was found significant at the level of 1% (P<0.01), the difference in the sugar content and refined sugar yield values was found significant at 5% (P<0.05).

Table 1 The comparison of conventional and seedling method

	Seedling method	Conventional sowing	Difference
Number of beet (root ha^{-1})	68,010 ±1,470	93,860 ±2,140**	-25,850
Beet yield (t ha^{-1})	47.34 ±1.82**	36.08 ±1.19	11.26
Sugar content (%)	18.22 ±0.25*	17.76 ±0.27	0.46
Refined sugar content (%)	15.88 ±0.25*	15.30 ±0.27	0.57
Refined sugar yield (t ha^{-1})	7.54 ±0.33**	5.52 ±0.22	2.02
Total cost ($ ha^{-1})	5,224.95	3,300.84	1,924.11
Pulp including gross income ($ ha^{-1})	4,517.49	3,357.86	1,159.63
Beet cost ($ ton^{-1})	110.37	91.49	18.88
Net income ($ ha^{-1})	-707.46	57.02	-764.48

(* P<0.05, ** P<0.01)

Table 2 General information of seedling planting method

Seedling cost for greenhouse ($)	0.044
Seedlings cost in the field ($)	0.046
Number of used units (unit ha^{-1})	82
Number of seedlings in the unit	1,400
Number of prepared seedlings	114,800
Number of planted seedlings	90,000
Seedling loss ratio between sowing and planting (%)	21.60
Average number of seedlings in harvest	68,010
Seedling loss ratio between planting and harvest (%)	24.43
Daily capacity of planting machine (ha)	0.7
Cost of wet pulp ($ t^{-1})	10
Seedlings beet price ($ t^{-1})	110
Conventional beet price ($ t^{-1})	92

Table 3 Total cost of the methods ($ ha^{-1})

Costs elements	Conventional Sowing	Seedling Method
Total fixed costs for the seedlings method (**Table 4**)	-	707.35
Total variable costs in seedling production (**Table 5**)	-	995.83
Cost of field production and protection (**Table 6**)	3,300.84	3,521.77
Total cost	3,300.84	5,224.95

Economic Evaluation

Total of fixed, variable, field production and plant protection costs calculated for economic evaluations of conventional sowing and seedlings trials are given **Table 2** and **Table 3**. The total general cost for seedling method was 5,224.95 $ ha^{-1}, fixed costs was 707.35 $ ha^{-1} (% 13.54), variable cost was 995.83 $ ha^{-1} (% 19.06), field production and protection cost were 3521.77 $ ha^{-1} (% 67.40) in the research. The conventional sowing method had only field production and protection cost and the sum of the cost was 3300.84 $ ha^{-1} (**Table 3**).

Material, instrument and equipment and its first investments costs (fixed costs) per hectare for seedling method are shown in **Table 4**. Transplanter, greenhouse frame, rotary tiller and polyethylene cover of greenhouse constituted the highest cost items in the table as 194.93 $ ha^{-1} (27.56%), 129.95 $ ha^{-1} (18.37%), 85.77 $ ha^{-1} (12.12%) and 77.97 $ ha^{-1} (11.02%) respectively. Seedling pots, sheep manure and transport and spare parts for machines constituted the significant costs items necessary to grow seedlings in the greenhouse as 376.17 \$ ha^{-1} (37.78%), 182.22 \$ ha^{-1} (18.30%), 133.20 \$ ha^{-1} (13.38%) respectively (**Table 5**).

Seedling production and protection cost for seedling method was 220.92 \$ ha^{-1} (% 6.70) higher than conventional sowing method. The reason of the difference was field preparation of seedling method needs a little more sensitive and used extra labor and traction power for transplanter (**Table 6**).

Comparison of conventional and seedlings method are shown in **Table 1**. Although taking 11.26 t ha^{-1} more products with seedling method, 764.48 \$ ha^{-1} less income was obtained from the conventional sowing method. Seedlings beet price was 110 \$ t^{-1} (**Table 2**). In this case beet equivalent of this amount was 764.48 / 110 = 6.95 t. It was necessary to obtain 11.26 + 6.95 = 18.21 t ha^{-1} more beets with seedling method in order to get equal income both conventional and seedling methods in terms of production cost.

Discussion

According to the results, seedling method was applicable method considered in terms of yields and quality in sugar beet agriculture.

Table 4 The initial investment costs of material, tool and equipment for seedling method

Materials, tools and type of equipment	Initial investment costs (\$)	Lifetime (year)	Annual costs (\$)	Annual used area (ha)	Annual costs per unit area (\$)
Greenhouse frame	6498	10	650	5	129.95
Polyethylene cover of greenhouse top	780	2	390	5	77.97
Polyethylene cover for greenhouse inside	260	4	65	5	13.00
Steel braces of greenhouse inside	585	10	58	5	11.70
Workplace and store	130	7	19	5	3.71
Soil sieving tools	552	10	55	5	11.05
Rotary tilling machine	4,288	10	429	5	85.77
Electric panel	52	10	5	5	1.04
Seed sowing plate	97	10	10	5	1.95
Soil and fertilizer mixer	1,040	10	104	5	20.79
Seedling carrying case	1,624	8	203	5	40.61
Upper cover paper	338	5	68	5	13.52
Bottom cover paper	312	2	156	5	31.19
Transplanter	9,747	10	975	5	194.93
Auto-seeder	3,509	10	351	5	70.18
Total	29,812		3,537		707.35

Table 5 Necessary variable costs to cultivate seedlings

Costs elements	Per unit (\$)				For 8.2 unit (\$)
	Labor	Traction power	Other	Total	
Sheep manure and transport cost	0.12	0.15	1.95	2.22	182.22
Sand and transport costs	0.09	0.23	0.16	0.47	38.90
Soil loading, sieving and transport	0.05	0.08		0.12	10.12
Greenhouse drain channel and snow cleaning	0.16			0.16	12.79
Fertilizer cost			0.10	0.10	8.53
Chemical cost			0.65	0.65	53.28
Soil preparation	0.05			0.05	3.73
Sowing	0.16			0.16	12.79
Maintenance	0.08			0.08	6.39
Top and side polyethylene (annually renewed 1/3 part)			0.46	0.46	37.83
Bottom cover paper polyethylene (annually renewed 2/3 part)			0.51	0.51	41.56
Seedling pots			4.59	4.59	376.17
Cover paper for irrigation			0.75	0.75	61.81
Harvest, loading and transport	0.20			0.20	16.52
Spare parts (for machinery)			1.62	1.62	133.20
Total	0.90	0.45	10.79	12.14	995.83

Seedling method provided a statistically significant increase (Brummer, 1975; Dillon *et al*., 1972; Dimsey R., 2009). It is clear that not an economical method in the case of producing seedlings within their own agricultural enterprises as much as their needs like in this research (Dimsey R., 2009; Heath and Cleal 1992; Scholz and Boe, 1984). Seedling method had approximately 58% higher cost compared to normal sowing method.

However, if the companies can supply of seedlings needs outsourcing instead of produce within their own enterprise, unit seedlings costs can be reduced and economic beet seedlings growing conditions can be created. Thus, yield and quality can be improved and lengthening the duration of beet growing period by early planting in the places like Ararat. The results not only in Ararat which and has short growing seasons, but also in all regions where the sugar beet agriculture performed can be obtained (Hubbell 1991; Theurer and Doney, 1980). Also, new employment and income areas can be generated by establishing new enterprises which will make seedling production in the sector.

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Table 6 Sugar beet cultivation and maintenance costs with conventional and seedling method

	Conventional sowing ($ ha^{-1})				Seedling method ($ ha^{-1})			
Costs elements	Labor	Traction power	Other	Total	Labor	Traction power	Other	Total
Soil preparation		227		227		260		260
Fertilization	13	52		65	13	52		65
Fertilizer price			273	273			273	273
Sowing	26	78		104				0.00
Planting				-	325	195		520
Thinning and singling	227			227				0.00
Hoeing	260	65		325	260	65		325
Irrigation	130	520		650	130	520		650
Harvest, Topping	520	260		780	520	260		780
Loading, unloading	78	52		130	78	52		130
Transport		195		195		195		195
Field rent			325	325			325	325
Total	1,254	1,449	598	3,300.84	1,326	1,598	598	3,521.77

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The Effects of PTO Options on Operational Characteristics of Disc Fertilizer Spreader

by

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Abstract

The objective of this research was to determine the effects of different tractor power take-off (PTO) options on working characteristics of single disc fertilizer spreader. The experiments were carried out for three PTO options, three gears and disc fertilizer spreader's three orifice position. In the study, the fertilizer spread patterns and evaluation parameters (fuel consumption, work width, effective field capacity and application rate) were determined. The experiments were conducted according to factorial experimental designs with 3 replications and examined effects of factors and their interactions on measurement parameters. In conclusion, the 540E PTO option provided the definite advantages in terms of fuel consumptions compared to the other PTO options. However, it was determined that 750 PTO option has some advantages on machine's work width and effective field capacity. In all applications trapezoidal pattern was produced by spinner spreader. Applications with 750 PTO option produced more uniform spread patterns than the other applications. Consequently, important knowledge for researchers and farmers using disc fertilizer spreaders were reported by considering the all experimental data.

Key words: PTO options, fertilizer spreader, spread pattern.

Introduction

The selection and using of suitable farm equipment is a necessity for a profitable production. The power take-off (PTO) mechanism of agricultural tractors is an important power supply for PTO driven farm equipment (Sümer *et al*., 2010a). The PTO driven farm equipment are operated at a standard PTO speed, but they need different torque and power levels to be operated effectively. Engine and transmission mechanism of tractors are designed to match the required power for PTO driven machines. The equipment that require low power at standard PTO speed (540 rpm (revolutions per minute)), unnecessarily consume more fuel because of high engine speeds (Goering, 1986; Sümer *et al*., 2010b).

To address this problem, tractor manufacturers developed transmission units that provide a standard PTO speed at lower flywheel speeds. The units, which have two transmission rates, are referred as 540E and 540. The 540E PTO option is also called "economical power take off". This option is also known as 750 PTO by farmers because transmission units, which provide 540E option, also provide 750 rpm PTO speed (Sümer *et al*., 2010a). The 750 and 540 PTO options are obtained at same engine flywheel speeds, but differ from 540E option. The 750 rpm is not a standard PTO speed but recently, it has become in use and known by farmers to operate the fertilizer applicators (Işıktepe and Sümer, 2010). Over 90% of the fertilizers in Europe are broadcasted by using spinner disc spreaders. The popularity of disc spreaders lies in their large working width, small size and low price (Olieslagers *et al*., 1996; Liedekerke *et al*., 2008). Researchers have carried out investigations to determine the fertilizer spread pattern and spreader's technical specifications. Parish (1996) investigated the selection, care and use of granular applicators. Olieslagers *et al.* (1996) examined the fertilizer distribution pattern of a disc spreader. Chaplin *et al.* (1995) researched the distribution pattern of fertilizer during field application. Hassan *et al.* (2005) conducted a study to improve spread pattern for different fertilizer types. Pettersen *et al*. (1991) carried out a study to determine the effects fertilizer particle size on spread pattern of a twin disc spreader. Fulton *et al.* (1999) conducted a research to quantify the distribution of a disc fertilizer spreader. Many researchers that have investigated the spinner spreaders have established some meaningful conclusions. But there is no investigation that includes using the different PTO options and evaluation of management parameters at the fertilizer spreader operations. The main target of best management practices of agricultural machines has become nowadays more important economically due to the consequent increase of fuel and worker wages all over the World.

The main objectives of this research were to; (1) Evaluate the effects of different PTO options on the operational characteristics of a single-disc fertilizer spreader, (2) Determine some operational management parameters, such as fertilizer application rate, effective field capacity, fuel consumption, pattern width, work width, and (3) Provide information for improving the performance of spreader by investigating the relationship between forward speed, PTO option, orifice position and management parameters.

Material and Methods

The experiments were performed on a field at the Agricultural Machinery Test Laboratory of the Çanakkale Onsekiz Mart University located in Çanakkale, Turkey. In the experiments, a single disc fertilizer spreader with a capacity of 350 liter was used. This machine was operated by New Holland TD85 tractor with a power of 62 kW. After the calibration, preparations of equipment and measuring systems were completed, some soil characteristics of the experiment field were determined. Soil type was sandy-loam and field was covered with grass. The cone index values measured between 0-80 cm depths were between 0.77 and 2.06 MPa. The moisture content values of the soil were found as average of 14.5% at 0-30 cm profile depths. The experiments which were performed using granular NPK fertilizer were conducted by using three gear levels, at three orifice positions, in three PTO options with 3 replications (**Table 1**).

In the experiments, ground speed, slip, fuel consumption, fertilizer spreader's work width, effective field capacity and application rate were determined. The fuel consumption was measured by using a flow-meter (Macnaught M05, Macnaught Pty. Ltd., Australia). In addition, relative humidity and ambient temperature were measured, and found between 17-22°C and 43-62%, respectively. The measured values are considered to be unlikely to affect other measurements. The slip was measured by using a magnetic sensor. The slip values varied between 7 and 10% for all the experiments. The fact that tractors operate with small loads can be shown to be an important factor for the small slip values. Slip values were determined to be close to each other in all operations since all the experiments were carried out on the same field surface.

The spread pattern testing is the critical step in obtaining an uniform distribution with disc spreaders. This test was necessary to determine the swath width and effective work width (Parish, 1996). The experiments were carried out by considering the methods of ASAE, American Society of Agricultural Engineers (ASAE, 2004). In the experiments, wooden trays that had 500 × 500 × 150 mm dimensions were used to collect the fertilizer thrown by machine for determining the fertilizer spread pattern and application rate. The collection trays, which have internal baffles to reduce the amount of fertilizer granule that bounces out on impact, were laid on the ground in a straight line perpendicular to the direction of disc spreader travel (**Fig. 1**). The spreader was then operated over the line of trays. The fertilizer collected in the trays was measured by weight at precision scales (with 0.1 gr accuracy) and the measured mass data used to calculate the spread pattern and application rate. Transverse tray testing are reliable means of determining distribution patterns and the interaction of machine components

Table 1 Technical specifications of experimental factors

Factors	Specifications		
PTO Options	540	540E	750
Speed (rpm) of PTO	540	540	750
Engine speed, rpm	2,200	2,200	1,715
Orifice Positions	O1	O2	O3
Sizes of orifices, mm^2	200	300	400
Gear Levels	G1	G2	G3
Gears	2-2	3-1	2-4

on fertilizer particle distribution but are difficult and time consuming to perform in on farm situations (Miller, 1996; Lawrence and Yule, 2007). The spreader's disc (spinner) was adjusted at 50 cm above the ground by taking into account works carried out by Sayedahmed (1989) and Hassan *et al.* (2005).

The line of trays extended at least far enough to each side to catch the farthest fertilizer granules thrown (swath width). Trays on tracks of tractor's both wheels were removed from the pattern to allow the disc spreader and tractor tires to pass through the line. It was accepted that fertilizer as much as average of fertilizer thrown into trays on both sides of each space fell into trays on the spaces.

The coefficient of variation (CV) is used to characterize the quality of distribution pattern by a spinner disc spreader (Parish, 1991). CV value usually was calculated with the standard deviation of application rate values across an overlapped spread pattern divided by the mean application rate and expressed as percentage. The lower CV means more uniform spread pattern. The CV varied from 5% to 10% for the transverse spread pattern of a spinner disc spreader at a reasonable work width (Parish, 1991). However, for most fertilizer spreading, it was expected that the CV could increase to 20% when conducting field tests. CV values of 20% are generally acceptable for most products (Parish, 1991; Sogaard and Kierkegaard, 1994). The CV % was calculated by using Equation 1 according to ASAE S 341.3 (2004):

$$CV\% = 100 \left\{\sqrt{\Sigma (Xi-Xa)^2 / (n - 1)}\right\} / Xa \quad \text{.......................................}(1)$$

Where Xi is weight of material in each tray (kg), Xa is average weight of material of all trays (kg), and n is number of trays. To determine the fertilizer spreader's effective and maximum work widths, subsequent passes of the equipment were overlapped adjacent spread patterns for a tray width on each respective side. CV values for each pattern obtained by overlapping were calculated. Distance between spreader centerlines in consecutive pass is the work width. The distance calculated in the lowest CV value was considered as the effective work width. The distance in the CV value closest to 20 percent was considered as the maximum work width. The effective field capacity (Sa, ha/h) was calculated by the following equation:

$$Sa = B\ V\ K \quad \text{.......................................}(2)$$

Where B is work width of machine (m), V is ground speed, (km/h), and K is field efficiency (decimal). The field efficiency had been used as 0.70 in accordance with the suggestion of ASAE which is limited between 0.50-0.75 (Bilgen and Sungur, 1992). Fuel consumption values per unit area (L ha^{-1}) were calculated by proportioning the fuel consumption values (L/h) measured in the experiments and the effective field capacity (ha/h) values. Variance analysis was performed by using Minitab R15 statistical software to determine the effects of PTO options, orifice positions and ground speeds on fuel consumption per unit time and area, work width and effective field capacity. Tukey test was used to compare the overall difference between the means.

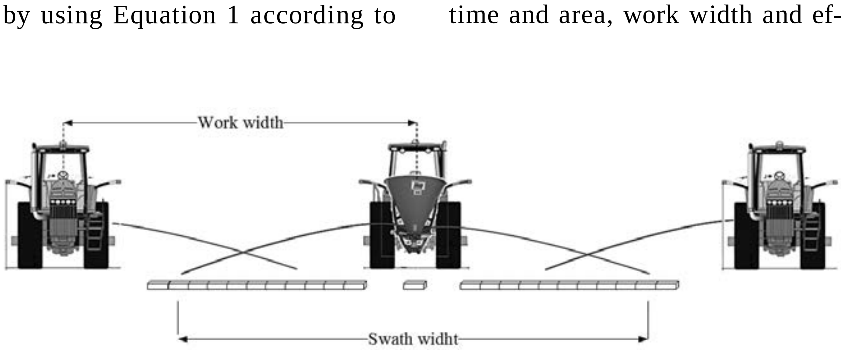

Fig. 1 The tray system for determining spreader distribution pattern

Results and Discussion

The effects of PTO options, orifice positions and ground speeds on operation parameters are shown in **Table 2**. The CV values that provide the effective work width values (by overlapping), varied between 3.95%-9.15%, while the CV that provide the maximum work width values (by overlapping) varied between 15.56%-19.99%. Piron and Miclet (2013) reported that the CV values were considered as poor if higher than 15%, as good between 5% and 10%, and as excellent if lower than 5%. According to this evaluation, Effective work width values determined by overlapping can be characterized as suitable (**Table 2**).

The parameters of application rate and effective field capacity were evaluated by considering effective and maximum work width. It was determined that the application rate decreased with ground speed increase while there is a positive relationship between the application rate and fertilizer orifice size. Also, it was found out that the PTO options were effective on application rate. The application rate tended to decrease gradually for 540E, 540 and 750 options, respectively. Increased ground speed from 540E to 750 explained the decrease in application rate. Similarly, Tawfik and Khater (2009) reported that the application rate had an inverse relationship with ground speed, and a direct one with fertilizer orifice size. They additionally emphasized that uniformity of pattern was highly affected by the spinner speed. Although the same gears were used in all of applications performed with three PTO options, it was determined to be differences among ground speeds measured. The notations given as G1, G2 and G3 describe the ground speeds obtained in 2-2, 3-1 and 2-4 gears, respectively. Working on the same gear levels, ground speeds in 540 and 750 PTO options were almost the same, but significantly lower at 540E option. This difference occurred as a result of lower engine flywheel speed associated with the 540E PTO option (**Table 1**). Sümer *et al.* (2010a) reported that the ground speed values decreased between 12.83% and 22.60% at field operations carried out with 540E PTO option compared to 540 PTO option. Increase in the ground speed has an effect in decreasing the fertilizer broadcasted per unit area.

Fig. 2 shows the shape and the swath width of the transverse spread pattern, considered perpendicular to the ravel direction. The shape of the patterns for three PTO options was trapezoidal as shown in **Fig. 2**. Trapezoidal pattern is known as the most ideal pattern profile, because of providing uniform application when properly overlapped (Parish, 1996; Liedekerke *et al.*, 2008). As mentioned before, the CV value is used to describe the quality of spread pattern produced by a disc spreader, and the lower CV means the more uniform patern (Parish, 1991; Sogaard and Kierkegaard, 1994). When comparing the CV values of spread patterns (without overlapping), it was determined that spread patterns produced by interactions with 750 PTO option

Table 2 Measurement parameters obtained in the experiments and some statistical values

				CV		Fuel Consumption		Effective Field Capacity, ha/h		Application Rate, kg/ha	
PTO Option	Orifice Position	Gear	Ground Speed, km/h	Min	Max	L/h	L/ha	Effect. Work Width	Max Work Width	Effect. Work Width	Max Work Width
540E	O1	2-2	4.26	5.13^{j}	16.83^{h}	2.54	0.57	3.83	4.47	134.98^{j}	115.69^{i}
		3-1	6.48	4.86^{k}	15.56^{l}	2.69	0.40	5.83	6.80	88.73^{p}	76.06^{o}
		2-4	8.22	4.42^{l}	19.99^{a}	2.88	0.33	7.40	8.63	69.95^{q}	59.96^{o}
	O2	2-2	4.26	7.62^{c}	18.74^{c}	2.54	0.57	3.83	4.47	246.48^{c}	211.27^{d}
		3-1	6.48	8.21^{b}	18.21^{e}	2.69	0.40	5.83	6.80	162.04^{h}	138.89^{g}
		2-4	8.22	5.71^{i}	17.20^{h}	2.88	0.35	7.40	8.32	127.70^{k}	113.54^{i}
	O3	2-2	4.26	7.22^{e}	18.69^{d}	2.54	0.55	3.99	4.63	366.20^{a}	315.69^{a}
		3-1	6.48	6.78^{f}	16.08^{k}	2.69	0.38	6.32	7.05	231.48^{d}	207.54^{d}
		2-4	8.22	4.61^{k}	18.57^{d}	2.88	0.32	7.71	8.94	189.78^{e}	163.60^{e}
540	O1	2-2	5.57	5.18^{j}	16.82^{h}	4.20	0.72	5.01	5.85	103.22^{n}	88.47^{l}
		3-1	8.38	4.20^{m}	16.00^{k}	4.29	0.49	7.54	8.80	68.64^{q}	58.83^{o}
		2-4	10.61	5.06^{j}	19.50^{b}	4.70	0.42	9.55	11.14	54.21^{s}	46.46^{q}
	O2	2-2	5.57	8.77^{a}	18.73^{c}	4.20	0.72	5.01	5.85	188.49^{e}	161.56^{e}
		3-1	8.38	8.17^{b}	18.40^{d}	4.29	0.49	7.54	8.80	125.34^{l}	107.44^{j}
		2-4	10.61	7.89^{c}	18.25^{e}	4.70	0.42	9.55	11.14	98.99^{n}	84.85^{l}
	O3	2-2	5.57	7.23^{e}	18.69^{d}	4.20	0.69	5.22	6.06	280.04^{b}	241.41^{b}
		3-1	8.38	6.76^{f}	16.07^{k}	4.29	0.47	8.17	9.11	179.06^{f}	160.54^{e}
		2-4	10.61	3.95^{n}	18.10^{f}	4.70	0.41	9.94	11.54	147.07^{i}	126.79^{h}
750	O1	2-2	5.51	6.21^{g}	16.69^{i}	4.48	0.70	5.58	6.40	92.82^{o}	80.84^{m}
		3-1	8.31	5.84^{h}	17.67^{g}	4.24	0.44	8.41	9.66	61.53^{r}	53.59^{p}
		2-4	10.52	7.68^{c}	17.06^{h}	4.59	0.36	11.05	12.62	46.85^{t}	40.99^{q}
	O2	2-2	5.51	6.76^{f}	18.45^{d}	4.48	0.70	5.58	6.40	169.50^{g}	147.63^{f}
		3-1	8.31	7.24^{e}	19.26^{b}	4.24	0.44	8.41	9.66	112.36^{m}	97.86^{k}
		2-4	10.52	6.10^{g}	16.53^{j}	4.59	0.38	10.65	12.23	88.72^{p}	77.27^{n}
	O3	2-2	5.51	9.15^{a}	19.26^{b}	4.48	0.68	5.78	6.61	252.95^{c}	221.33^{c}
		3-1	8.31	7.36^{d}	19.13^{c}	4.24	0.41	9.03	10.28	161.90^{h}	142.28^{f}
		2-4	10.52	6.35^{g}	18.03^{f}	4.59	0.36	11.05	12.62	132.40^{j}	115.85^{i}
P value											
PTO Option			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Orifice			1.000	0.000	0.000	1.000	0.201	0.000	0.000	0.000	0.000
Speed			0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PTO*Orifice			1.000	0.000	0.000	1.000	1.000	0.386	0.837	0.000	0.000
PTO*Speed			0.000	0.000	0.000	0.165	0.006	0.000	0.000	0.000	0.000
Orifice*Speed			1.000	0.000	0.000	1.000	0.992	0.001	0.096	0.000	0.000
PTO*Orifice*Speed			1.000	0.000	0.000	1.000	1.000	0.656	0.375	0.000	0.000

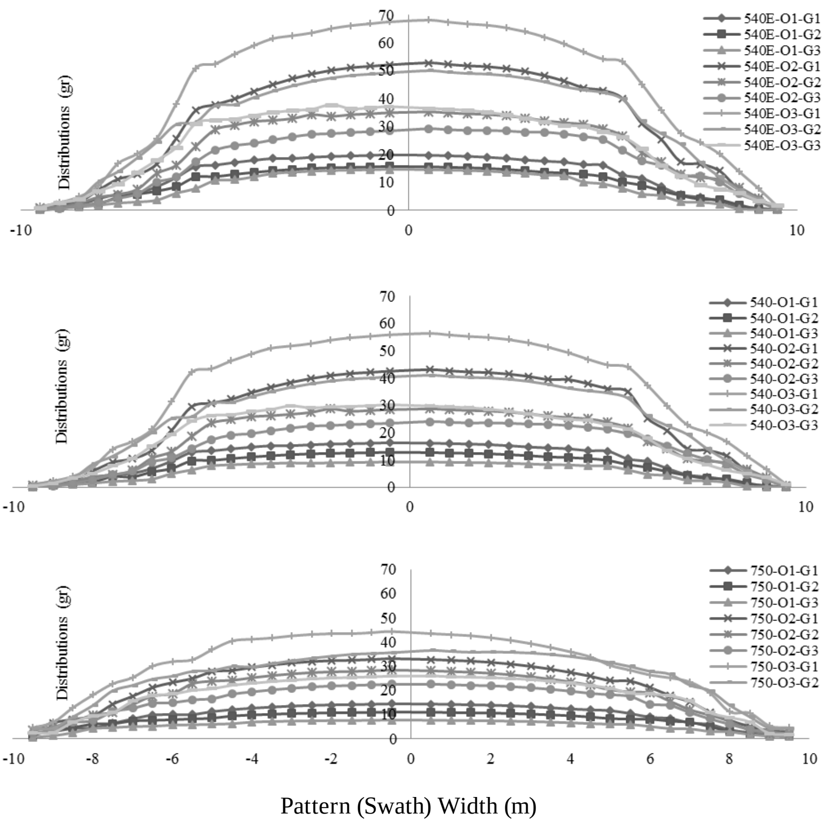

Fig. 2 Spread pattern

have lower CV values rather than that of other PTO options. CV values determined for 540E, 540 and 750 options were 55.98%, 55.70% and 43.76% in average, respectively. Relationship between CV values and interactions can be also seen in **Table 2** and **Fig. 3**.

When considering the effective and maximum work width values, for each selected fertilizer spread patterns, it was determined that there was not a significant difference between 540 and 540E PTO options. However, 750 PTO option provided an increase of the work width (**Table 2**). 540 and 540E options did not differ from each other in terms of rotation (rpm) transferred to spreader. The spinner rotates at the same speed for these two PTO options. Spreader disk rotates with speed of 210 rpm more at the 750 PTO option. This situation resulted in the increase of about 12% in work width. While the effective

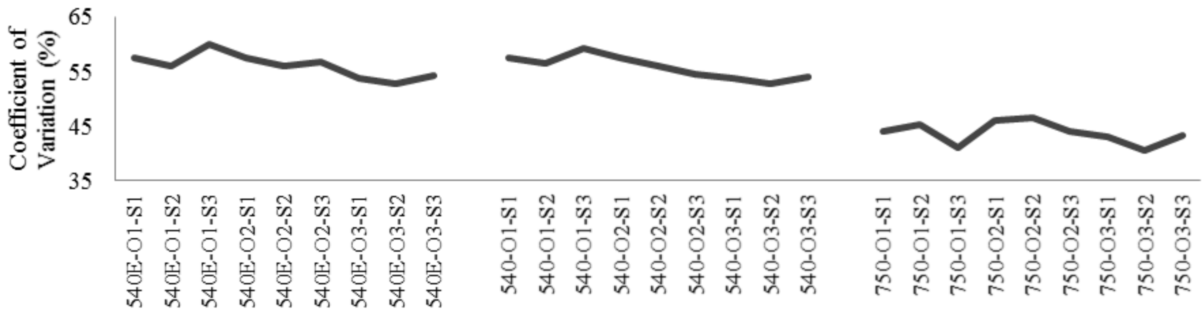

Fig. 3 Relotionship between CV and interactions

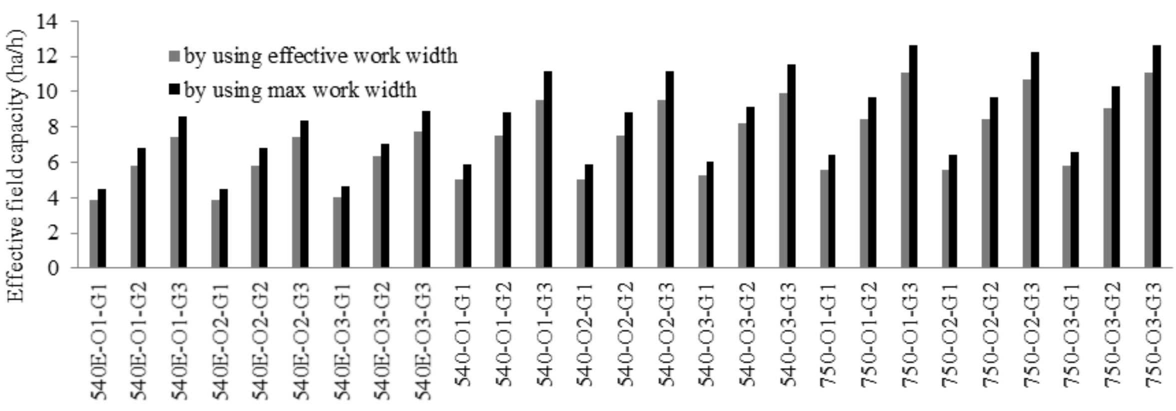

Fig. 4 Relationship between effective field capacity and interactions

work width (about 14 m) was provided by overlapping of 5.5 m with 750 option, for other PTO options, effective work width (about 12 m) was provided by overlapping of 7 m. When the work width values were examined, it was determined that fertilizer orifice positions had no significantly effects on work width (**Table 2**).

In the applications, it was found that the ground speed had an impact on the effective field capacity. For instance, when applications included only one of the PTO options that were examined; it was seen that increasing the ground speed caused an increase in effective field capacity. Besides, it was found that effective field capacity, with the applications using 540E option, decreased compared to other two PTO options (**Fig. 4**).

The considering of fuel consumption values (L/ha) calculated by using of fuel values consumed as volume per unit time and effective field capacity values (ha/h) was a more reasonable approach than fuel consumption per unit time for evaluating the fuel consumption of tractor (Sümer *et al.*, 2010b). Sümer *et al.* (2010a) carried out field experiments to determine the effects of economical PTO speed on operational characteristics of some PTO driven machines in field conditions. Sümer *et al.* (2010b) also compared the 540E and 540 PTO options in tractors through laboratory tests and reported that there was significant difference between two PTO operations (540 and 540E) in terms of fuel consumption per unit time and area. However, the differences between each other of three PTO options in stated studies were not investigated. As mentioned before, 540E option is achieved at lower engine speed than that of 540 and 750 options and the difference between the engine speeds is 485 rpm. Fuel savings is related to the amount of decrease in engine speed. The fuel consumption per unit area for 540E option compared to other PTO options (540 and 750) was reduced. The 540E option, when the average fuel consumption per unit time are considered, provides a savings of 38.51% and 39.06% compared to 540 and 750 options, respectively. However, according to the average fuel consumption values per unit area, the 540E option provides a savings of 20.06% and 13.67% compared to 540 and 750, respectively (**Fig. 5**, **Table 2**). Işıktepe and Sümer, (2010) investigated the differences of operational characteristics between the 540 and 750 PTO options in tractors at the laboratory condition and concluded that the 750 PTO operations had higher fuel consumption values (L/h) than those of the 540 PTO operations. As shown in **Table 2**, this report was confirmed in this study. But it was determined that the effective field capacity values obtained in the applications with 750 PTO option were lower by 8% than that of 540 PTO option. This difference provided an advantage ith the view of fuel consumption per unit area for 750 option compared to 540 option (**Table 2**).

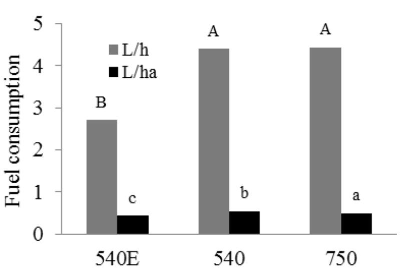

Fig. 5 Relationship between fuel consumption and PTO options

According to the fertilizer spread patterns produced by experiments, the highest amount of fertilizer was broadcasted by 540E*O3*G1 interaction, the lowest broadcasting occurred 540E*O1*G3 interaction. When spread patterns produced by applications with 540 and 750 PTO options were examined, the highest broadcasting of fertilizer achieved at O3 orifice position and G1 gear level, while the lowest one occurred at O1 orifice position and G3 gear level (**Table 2**).

Conclusions

An experimental research was performed to investigate the effects of PTO options, orifice position and ground speed on some operational characteristics of a spinner spreader. The research was especially focused on the ability to use of PTO options, which is an alternative to the standard 540 PTO option. According to the CV values used to evaluate the quality of spread pattern produced by a single disc spreader, the 750 PTO option provided more uniform pattern than those of the 540 and 540E PTO options. Furthermore, the 750 PTO option had lower fuel consumption values per unit area compared to the 540 PTO option, because of having higher effective field capacity values owing to increase of about 12% in effective work widths. Economical (540E) PTO option provided the lowest fuel consumption per unit time and area among PTO options tested in this experiments. But it has disadvantage in terms of effective field capacity, because of providing lower ground speed than those of other PTO options. In order to choose the appropriate one of the PTO options, all parameters determined in research should be considered. Effective field capacity and fuel consumption parameters included considerable indications that can be especially useful to selecting a PTO option.

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Investigation of Grain Distribution Characteristics in an Axial Flow Thresher Using Impact Sensors

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Abstract

Assessing grain distribution characteristics of an axial flow thresher is significant in its design and performance evaluation. These characteristics can be determined by partitioning the stationary thresher along its axis and then measuring the average grain collected in each compartment, which is a cumbersome work. To overcome these practical hindrances a different approach has been proposed and implemented in this paper which involves the precisely selected silicon-implanted piezo-resistive force transducers (Make: Honeywell, Model: FSG15N1A). Each transducer was separately connected to micro-computer through a signal conditioning circuit with appropriately adjusted signal gain which senses the number of wheat grains falling on it with a particular force. Daisy Lab software was used to collect data on micro-computer. The result showed that the grain separation/collection was initially less it rapidly increased and then exponentially decreased along the axial length of thresher. The key results were verified with the already established experimental method. The trend showed that about 80% of total grains got separated and collected in the first 47.67% of the total thresher length.

Introduction

Threshing is an essential process of loosening the edible part of crop from inedible chaff that surrounds it. Presently, threshing is mostly accomplished by machines known as threshers. The most commonly used threshers in India are either tangential flow or axial flow threshers.

The axial flow thresher was developed at International Rice Research Institute (IRRI) in late 1970. In these threshers, the crop moves spirally between the cylinder and concave along the axis of the cylinder. The rotor threshes the crop by the combined action of rubbing, impact and centrifugal force. The axial forward movement of the crop inside the thresher is provided by louvers attached on the top cover of threshing cylinder. The cylinder to concave clearance in this thresher is more as compared to tangential flow thresher; accordingly a gentle threshing action occurs with less breakage of grains. Large numbers of axial flow threshers are manufactured in India and most of these are fundamentally based on the designs of IRRI axial flow thresher. At present more than 25,000 axial flow threshers are manufactured in Punjab and sent to other parts of the country. The percentage of visible and invisible grain damage in existing threshers is 4.49% that includes harvesting losses (Anon, 2011). This is higher than Indian Standards limit of 3% (IS 11691, 1986) and international limit of 1% for cereals (Anon, 2001). Hence there is a need to redesign the thresher by changing its threshing length to reduce these losses. The optimum threshing length can be estimated by determining the grain distribution characteristics of a thresher. The present method to determine grain distribution character is by dividing the threshing cylinder length in number of equal parts and making compartments according to these parts. In this method the cleaning unit of thresher is to be removed and compartments are fitted in its place. Thus it is a very laborious process. Force sensors can be used in place of compartments to determine the grain distribution characteristics of axial flow threshers by mounting them below concaves without removing the cleaning unit.

Bjork (1991) presented a study of rotary combine for winter wheat to determine the grain separation characteristics of the combine. Grain separation in small areas with assigned co-ordinates, total separation and separation losses were measured for different feed rates and rotor speeds. Grain separation was measured at 16 locations in a grid pattern underneath the concaves and separating grate. Harrington (1970) designed a multi crop thresher. The clearance between concave and spike tooth was kept at 2.5 cm. The losses in paddy and wheat were 3%. Cylinder speed of 800-1,000 rpm resulted in less than 0.1% visible damage and unthreshed grains were less than 1.0%. Newberg *et al.* (1980) evaluated the damage to soya bean caused by rotary and conventional threshing mechanism. The percentage of splits was significantly higher for the conventional cylinder than for single or double rotor threshing mechanism at similar peripheral speeds. Chabbra and Singh (1977) determined the optimum cylinder speed and peg spacing of IRRI axial flow thresher to use it for wheat threshing. The optimum cylinder speed of 700 rpm and peg spacing of 63.5 mm were obtained. Joshi and Singh (1980) developed Pantnagar-IRRI multi-crop thresher. It combined the features of IRRI axial flow rice thresher and peg type wheat thresher. Joshi (1981) studied the use of mechanical threshers based on the functional requirements, level of performance and economy to present the information which could be useful for the selection of thresher parameters. Multi-crop thresher was designed, developed and evaluated by Sharma *et al.* (1983). The machine worked satisfactorily on wheat, paddy and maize. Sharma *et al.* (1984) developed a wheat-cum-paddy thresher. The machine had a wheat straw bruising attachment which could be removed while threshing paddy. Khan (1986) investigated for threshing freshly harvested paddy axial flow concept to reduce the machine weight. Quick (1998) presented a classification and the overall characteristics of various types of power threshers as a set of baseline data to assist in future thresher design. The advantages and disadvantages of several types of threshers had been compared. Bansal and Lohan (2009) developed an axial flow thresher for seed crops with visible seed damage 12% and threshing efficiency 95%. Threshed seed germination percentage was more than 85%.

Dogra (2005) conducted a study on composite tangential cum axial flow combine. During the evaluation, cleaning unit was replaced with collection chamber. Three equally divided portions of axial cylinder along the length were made for collection of grain straw samples. Grains falling through axial portion followed exponentially decreasing function along threshing length. Miu and Kutzbach (2008) carried out modeling and simulation of grain threshing and separation and separation in axial threshing units to develop a mathematical model that quantified the threshing and separation process. The mathematical model was validated using reliable experimental data. Acoustic impact sensors were used by Liu and Leonard (1993) to describe the real time monitoring of grain loss from the rotor of axial flow combine. Acoustic sensors were placed below separating grate in three by three configurations. Sensors data was converted into exponential grate curve describing the grain separation around the separating grate. The grain losses were determined by extrapolating the curve from the grate end to infinity. The actual and predicted losses were same at 95% probability level.

This paper presents an agro-electronic approach to evaluate grain distribution characteristics of an axial flow thresher by mounting force sensors appropriately inside the thresher cylinder. The key results so obtained have been validated with the experimental findings to verify the proposed method.

Materials and Methods

Assessing grain distribution characteristics of different axial flow threshers by using compartments below concave and separation grate is a laborious work which consumes lot of time and requires more man force. To overcome these practical hindrances, an attempt has been made to place force sensors inside the thresher cylinder suitably for the determination of grain distribution characteristics of an axial flow thresher and compared the key results with the experimental findings.

Experimental Test Rig

An axial flow stationary threshing unit encompasses features of tangential crop feeding and axial threshing was utilized for developing and implementation of this approach. Seven louvers at an angle of 20° were provided on the top cover of threshing cylinder with spacing of 120 mm between them (Sharma *et al.,* 1984). Cylinder to concave gap on feeding side and rear side was kept at 25 mm. The cylinder was rotated at 650 rpm. Rotor length including thrower was 1,250 mm. An open rotor was used that has centrally supported mild steel shaft of 50 mm diameter and three supporting disks. The rotor tip diameter, including spike length of 120 mm, was 700 mm. The eight rows of spikes were mounted in staggered manner with each row had five spikes. Spacing between the rows was kept 160 mm. A concave wrap angle of 120° with round bars was used with spacing of 20 mm. The diameter of round bars was 10 mm and length of the concave was 930 mm. The diameter of casing had been kept 780 mm. The evaluation of test setup was carried out on the wheat crop variety PBW 590.

Compartments

The thresher housing length has been partitioned perpendicular to the rotor axis into four compartments with galvanized mild steel sheets of appropriate size. A duct was provided in every compartment to remove and collect grains from it. Width and depth of each compartment was 697 and 280 mm respectively. Length of 1st, 2nd, 3rd and 4th compartment was 387, 310, 304 mm and 461 mm respectively. The compartments are represented by C1, C2, C3, C4 and their arrangement plan is shown in **Fig. 1**.

Force Sensors

Specialized piezo-resistive micro machined silicon force sensors (Make: Honeywell, Model: FS-G15N1A) were selected to record an impact over a wide range of force. A particle hit over the surface of sensor generates a pulse when connected suitably with a specified signal conditioning circuit. Pulse so obtained was transmitted through an untwisted pair cable (CAT-5) and recorded by micro-computer using Daisy Lab software. Thus the number of pulse count gives the number of grain strikes.

To overcome the problem of behavioral mismatching in silicon devices, seven sensors with near similar characteristics have been critically identified and utilized from a group of 24 sensors. The identification process was carried out by individually connecting a sensor to the same signal conditioning circuit when subjected to two different weights of W1 (441.6 gm) and W2 (491.6 gm) respectively. Accordingly the output voltage of every sensor for each weight was observed. Out of 24 sensors only seven were picked up whose output voltage for the chosen weights was within the range of ±2.19% as shown in **Table 1**. These selected sensors were properly insulated and mounted on a rectangular iron bar which was fixed on the concave in such a way that the position of 1st, 2nd, 3rd, 4th, 5th, 6th, and 7th from the front end of thresher housing was 212, 347, 482, 622, 757, 892 and 1,022mm respectively. Each selected sensor was connected to micro-computer through a paired cable and a conditioning circuit with appropriately adjust signal gain. **Fig. 1** illustrates detailed layout plan of seven force sensors, marked as encircled 1, 2, 3, 4, 5, 6 and 7 respectively, within the thresher housing as well as their compartment wise position.

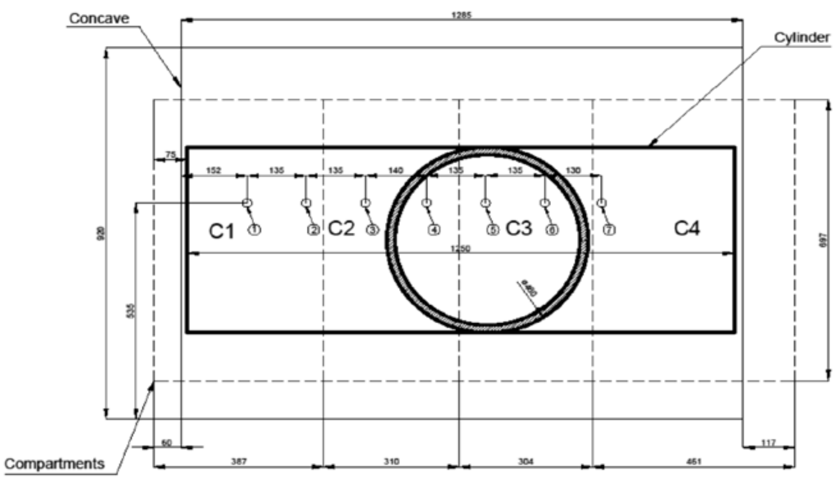

Fig. 1 Force sensors arrangement in compartments

Evaluation Procedure

For evaluation of sensors wheat crop of variety PBW 590 was used. The moisture content of the straw and grain was within the range of 15% to 20% and 10% to 11% respectively. Power Takeoff Shaft (PTO) was connected to the thresher using square PTO link. Data logger of force sensors was powered on before running the thresher and is connected to laptop with d-link CAT-5 cable to get readings. Speed of cylinder for threshing was kept constant at 650 rpm (within the percentage error of ±0.46%) during the experimentation. A feed of ten bundles, one after the other, was given to the thresher. During threshing process, sensors count only those grains which strike on them with specific force. After the feeding of ten bundles, thresher was stopped. Threshed grains collected in different compartments were taken out

Table 1 Voltage output of sensors with known weights

Output Voltage	
W1	W2
0.091	0.099
0.091	0.099
0.090	0.097
0.089	0.097
0.093	0.101
0.092	0.100
0.093	0.100

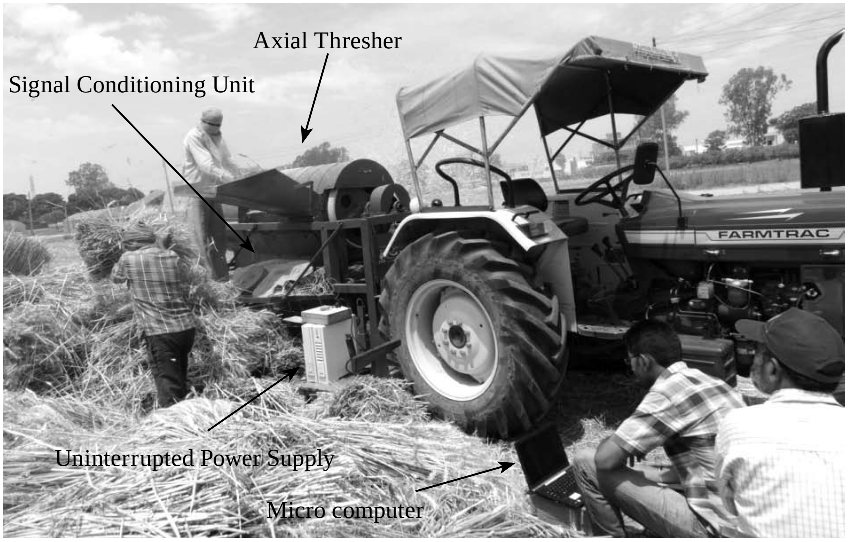

Fig. 2 Complete Experimental Setup

separately and collected in various marked gunny bags. Compartment number and reading number were written on each gunny bag with the help of marker. After this, the compartments were closed by door bolt. Same procedure was repeated to take 10 sets of readings. Then these samples were winnowed using power cleaner. Cleaned grains were weighed on electronic weighing balance according to compartment and weights were recorded. The complete prototype experimental set up is shown in **Fig. 2**.

Results and Discussion

The number of grain counts per sensor was recorded and the average number of counts per sensor was calculated compartment wise for ten replications represented as R1 to R10 in **Table 2**. It is illustrated that initially average grain count increased sharply and then started decreasing exponentially along axial length of thresher.

Grains were collected from each compartment and sample was win-

Table 2 Number of counts with force sensors mounted at different positions along the axial length

Sensor Position (mm)	Number of counts recorded in ten different replications										Average Count
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	
212	1	3	7	6	0	4	2	4	3	2	3.2
347	14	3	3	4	12	7	4	5	6	4	6.2
482	5	3	6	7	5	5	1	2	2	2	3.8
622	2	2	3	2	3	2	1	1	1	1	1.8
757	1	1	2	3	2	1	1	1	1	1	1.4
892	2	1	1	1	1	1	1	2	1	1	1.2
1,022	1	1	1	1	1	1	1	1	2	1	1.1

Table 3 Weight of the Grains collected in each compartment

Compartment Number (Size, mm)	Grain weight collected during each reading set (kg)										Average Weight (Kg)
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	
C1 (0-387)	4.43	4.95	3.83	3.61	3.96	3.73	3.28	3.16	3.19	3.99	3.813
C2 (387-697)	2.46	2.58	2.6	2.05	2.1	2.44	2.39	2.12	2.15	2.62	2.351
C3 (697-1001)	1.17	1.02	1.24	1.56	1.88	1.24	1.43	1.07	0.94	1.21	1.276
C4 (1001-1462)	0.31	0.43	0.43	0.43	0.66	0.66	0.66	0.47	0.44	0.51	0.5

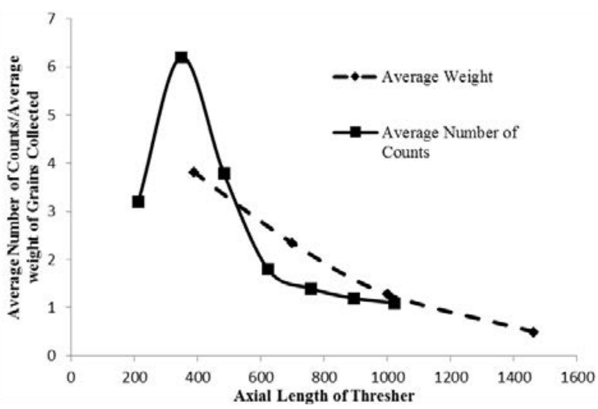

Fig. 3 Compartment wise average number of counts and weight of grains

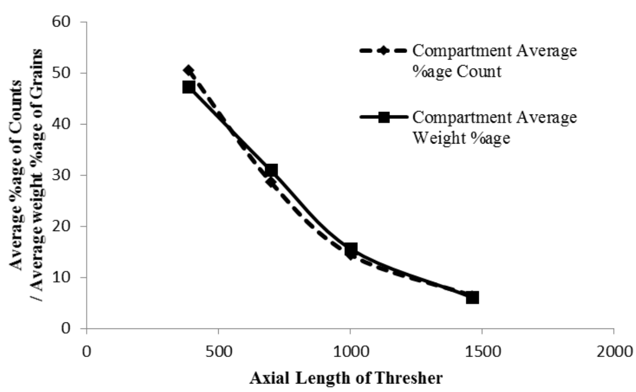

Fig. 4 Compartment wise %age of grains

nowed separately and weighed. The **Table 3** depicts that the physical weight of grains collected in very first compartment is more and it gradually decreases in 2nd, 3rd and 4th compartment respectively. The minor discrepancy in the trend of **Tables 2** and **3**, which is shown graphically in **Fig. 3**, is because of the width of first compartment. Spatial placement of sensor S1 and S2 was in first compartment at different locations along the length, thus the total average count of sensors S1 and S2 corresponds to total weight of grains collected in this compartment.

An average percentage count of each compartment was calculated and is shown in **Table 4**. It is revealed that about 79.17 percent of total grains got separated in first two compartments. Actual percentage of weight of the grains separated in each compartment was determined and is depicted in **Table 5** which also indicates that about 78.252 percent of total grains got separated in the first two compartments. The results obtained in **Tables 4** and **5** were illustrated graphically in **Fig. 4** and are in close approximation. The variation of compartment average percentage count from compartment average weight percentage was 6.7%.

Conclusions

The experimental results depict that the average count of grains increased sharply, became maximum and then decreased exponentially along the axial length of the thresher. The trends recorded by the average percentage count of force sensors were very much in close approximation to the physical weight of collected grains in each compartment. About 80% of total grains become separated in the length of first two compartments. The present study concluded that the application of force sensors could be a good option for the future design considerations of axial flow wheat thresher.

Table 4 Percentage of counts in each compartment

Replication Number	Percent of the total counts by the sensors mounted in different compartments			
	C1	C2	C3	C4
	S1, S2	S3, S4	S5, S6	S7
R1	57.69	26.92	11.54	3.84
R2	42.86	35.71	14.29	7.14
R3	43.48	39.13	13.04	4.35
R4	41.67	37.50	16.67	4.16
R5	50.00	33.33	12.5	4.16
R6	52.38	33.33	9.52	4.76
R7	54.54	18.18	18.18	9.09
R8	56.25	18.75	18.75	5.25
R9	56.25	18.75	12.5	12.5
R10	50.00	25.00	16.67	8.33
Compartment Average %age Count	50.51	28.66	14.37	6.36

Table 5 Percentage of weight in each compartment

	Data in percentage according to weight			
Replication number	C1	C2	C3	C4
R1	52.92	29.39	13.9	3.7
R2	55.12	28.78	11.35	4.78
R3	47.28	32.1	15.3	5.31
R4	43.97	32.27	19	5.23
R5	41.25	32.29	19.58	6.87
R6	47.13	30.07	16.81	6.97
R7	46.22	30.23	15.36	8.18
R8	46.33	31.08	15.69	6.89
R9	47.47	31.99	13.99	6.55
R10	45.18	31.45	14.52	6.12
Average %age grain weight in each compartment	47.287	30.965	15.55	6.06

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Transducers for Measurement of Draft and Torque of Tractor-implement System—A Review

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Abstract

Tillage is the primary operation in agriculture and represents a considerable amount of energy utilized for crop production. It is estimated that 20 to 55% of the available tractor energy is wasted at the tire-soil interface. Minimum power consumption and improved operating efficiency can be obtained by ideal matching of tractor and implement. This can be achieved by measuring the draft force and drive wheel torque required by tillage implements. It is a prominent factor during selection of machinery and power source of tractor. The simultaneous measurement of draft force and drive wheel torque of tractor may enhance the performance of the tractor. Telemetry based embedded system can be developed for simultaneous measurement of draft force, wheel slip and drive wheel axle torque of tractor. Based on the availability of the torque, wheel slip and draft force required by tillage implements, farmer have the choice and flexibility in selection of implements and power sources.

Key words: Drawbar pin, dynamometer, embedded system, strain gauge transducer, telemetry system.

Introduction

Farm input energy management is very important in crop production. This will be brought about by the increased cost of all forms of energy and the need to do field operations and produce crops with optimization of inputs (Chaplin *et al*., 1987). The research result shows that 20 to 55% of the available tractor energy is wasted at the tire-soil interface. In addition to wasting energy, improper ballast can cause excessive tire wear or soil compaction (Burt *et al*., 1982). The aim of tillage operation is to improve the soil physical condition for seed germination and crop growth. The effectiveness of the tillage operation is mainly depends on the forward speed of the implement and the power unit used to pull it through the soil. Availability of draft and torque requirement data for tillage implements is an important factor in matching of tractor-implements combination and estimating the fuel consumption for a particular farming situation (Thomson and Shinners, 1989; Askari and Smail, 2013 and Alimardani *et al*., 2008). These parameters decide the cost of cultivation, operational efficiency and benefits to the farmers. Also ownership and operating costs of both tractors and implements can be minimized by using accurate draft requirement data. A farmer mostly depends on past experience for selecting tractor and implements for various farming operations. The previous experience may have little effect in selecting newly available implements. Tractor-implement operating efficiency depends heavily on how well the tractor and implement are matched. When ideally matched, there is less power loss, improved operating efficiency, reduced operating cost and optimum utilization of capital on fixed costs (Taylor *et al*., 1991). The objective of this paper is to overview the existing transducers for accurate measurement of draft and drive wheel torque required by tillage implements and identification of proper technology to improve operational efficiency.

Transducers for Draft and Driving Torque Measurement

In general, measurement of draft required by tillage tools is accomplished by dynamometers. These are grouped into two major categories; drawbar dynamometers and three - point hitch dynamometers. Drawbar dynamometers are designed to measure the forces exerted by pull type implements on the tractor drawbar. These are extensively studied by many researchers (Godwin, 1975; Zoerb *et al*., 1983; Godwin *et al*., 1993; Kirisci *et al*., 1993; Chen *et al*., 2007). Mounted implements necessitate the use of three-point hitch dynamometers to determine the forces between the tractors and implements (Aljalil *et al*., 2001). Wheatstone bridge with strain gauges had been extensively used in development of force transducers. Anderson *et al*. (1974) developed a wheel torque meter with conventional strain gauge techniques to measure applied torque on drive wheels. A frequency modulated inductive coupling method was used to transmit the torque signals from the revolving wheel to a stationary recorder on tractor. The common method of measuring tractor axle torque is by using a set of strain gauges with slip rings mounted either at the outer end of the axles or on the top of the wheel mudguard to transfer the strain gauge signals to stationary recording equipment (Tompkins and Wilhelm, 1982; Malcolm *et al*., 1985; McLaughlin *et al*., 1993).

Measurement of Drawbar Forces of Tillage Implements

Drawbar force can be measured by transducers such as hydraulic dynamometers, mechanical dynamometers or by electrically instrumented dynamometers. Precision and accuracy of measurements are comparatively higher in electrically instrumented dynamometers. The first attempt was made to measure the forces between tractor and mounted implement by measuring the forces in links themselves (Khan *et al*., 2006). It required a simultaneous recording of at least three forces and involved very complicated instrumentation. Reece (1961) developed a strain gauged pins for measuring the draft of a three-point link implement. These pins could only measure longitudinal component of force in each link and were only suitable for free linkage systems. Force transducer type drawbar pins were developed to measure the draft force (Zoerb *et al*., 1983).

The complications of the drawbar pins necessitate the development of drawbar dynamometers and are grouped into frame type and linkage type. A frame type dynamometer consists of transducers mounted on a specially constructed frame which is inserted between the tractor and the implement and a linkage type dynamometer has the force transducers built within the hitch links (Thomson and Shinners, 1989; Kirisci *et al*., 1993). Altering the position of implement relative to the tractor is avoided in linkage type dynamometers, which enables the flexibility of an operation. Hoag and Yoerger (1975) developed most durable linkage type dynamometers, which include a plain extended rings and extended octagonal rings (EOR) (**Fig. 1a**). Both are relatively compact and have a massive central section to which loading fixtures can be bolted. Strain gages are mounted on the thinner ring sections for force measurement. The extended octagonal rings are capable of measurement of draft and vertical forces and pitch moment. Furthermore, many authors developed different capacities single and double extended octagonal rings on same operating principle (Godwin 1975; O'Dogherty 1975; Godwin *et al*., 1993), the capacities ranges up to 1.5 kN. For higher capacities Chen *et al*. (2007) developed a 2D double extended octagonal ring (DEOR) drawbar dynamometer. Two extended octagonal rings were used to reduce the designed load by half and were oriented vertically on either side of the tractor drawbar, which provided a better match of strain to expected drawbar draft and vertical load than a horizontal orientation in previous designs (**Fig. 1b**) (Leonard, 1980; McLaughlin *et al*., 1998). Both drawbar pins and octagonal ring type force transducers measures the forces during single hitch point conditions. Theses transducers fail to satisfy the measurement of forces in

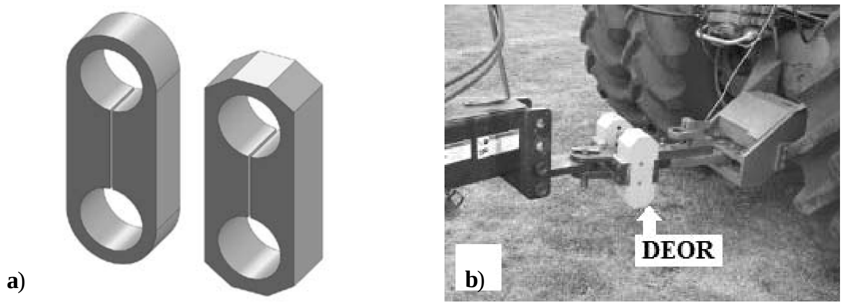

Fig. 1 Ring type transducers: **a**) plain extended ring and extended octagonal ring (EOR); **b**) DEOR dynamometer. (Hoag and Yoerger, 1975; Chen *et al*., 2007)

two and tree point hitch system.

For two point and three point hitching conditions, forces acting between the tractor and implement measured by using a six point dynamometer suspension system using load cells (Baker *et al.*, 1981; Chaplin *et al.*, 1987). Kirisci *et al.* (1993) mounted the strain gauges directly on the lower links of the tractor. Khan *et al.* (2006) also developed a bi-axial direct mounted strain gauged lower links system for the measurement of tractor-implement forces. The developed system was working well for a range of draught and vertical forces up to 20 kN. An adjustable type of three - point hitch dynamometer was developed by Al-jalil *et al.* (2001), which is suitable to the standard and non-standard size implements (**Fig. 2**). The dynamometer consisting of three telescoping beams connected to a central T-shaped box. Different width and height of the dynamometer can be adjusted to satisfy the variable dimensions of the implements. The strain gages attached to the cantilever beam with wheat stone bridges to measure the draft forces. To use the PTO simultaneously with three point hitch dynamometer Alimardani *et al.* (2008) developed a chassis type three point hitch dynamometer system. The chassis is in a reversed U-shaped frame which allows using PTO at the same time. With the strain gages installed on the three sensing pins to measure the draft forces in each link in addition to vertical forces on the lower links.

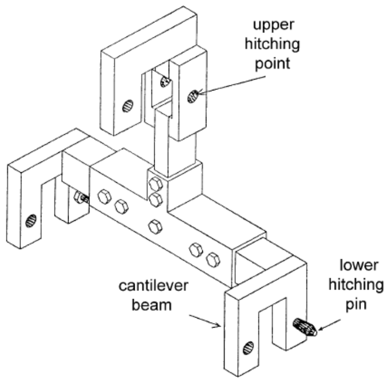

Fig. 2 Adjustable three point hitch dynamometer (Al-jalil *et al.*, 2001)

Askari *et al.* (2011) also developed an adjustable three-point hitch dynamometer. The design was based on two linkage frames mounted between tractor links and the implement. Load cells were used as a force sensing unit, which were installed between the frames. The system suited to wide range of implements by variable width and depth adjustment of dynamometer. All mounted tillage implements at categories II and III such as plows, cultivators and harrows were able to be tested by this dynamometer excluding mounted implements powered by power take-off (PTO). This dynamometer limits the use of PTO simultaneously with the drawbar. Tewari *et al.* (2012) developed a three-point hitch dynamometer to measure the draft of mounted implements. The developed system mainly consists of four parts including the arms with extension for left and right, sensing components, inverted T frame and a head bar (**Fig. 3a**). The force sensing elements comprised of three load cells, which were inserted between the frame and the hook brackets. It can be fitted to any tractor-implement combination. The front end of this frame attached to the tractor and the rear end attached to the implement (**Fig. 3b**).

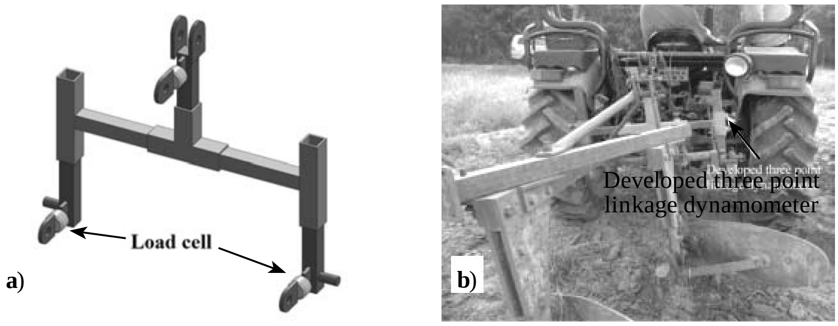

Fig. 3 **a**) Developed Three point linkage dynamometer, **b**) Field testing of the developed three point hitch dynamometer with an implement (Tewari *et al.*, 2012)

Drawbar performance indicates the pulling ability of the tractor. It mainly depends on availability of torque on driving axles, thrust force development at drive wheel contact with ground and wheel slippages. Whereas the thrust force development and wheel slippages are dependent on drive wheel torque, wheel characteristics and soil conditions. Some researcher's tried to improve the operational efficiency by measuring drive wheel torque.

Measurement of Drive Wheel Torque of Agricultural Tractors

Drive wheel axle torque indicates the availability of the axle power for traction. By measurement of this torque, tractor performance can be optimized and avoids the wastage of energy. Vertical soil reaction monitors the dynamic axle load as vehicle moves on different ground profiles. This reaction can be measured by developing an instrumentation of the system (Bentaher *et al.*, 2006; Nang *et al.*, 2009; Al-Suhaibani *et al.*, 2010). Instrumentation that measures the wheel torque and angular velocity would enable the traction of the drive wheel to be investigated. Some researcher found a common method for wheel torque measurements was strain gauges with a slip ring mounted either at the outer end of the axles or on the top of the wheel mudguard to transfer the strain gauge signals to stationary recording equipment (Tompkins and Wilhelm 1982; McLaughlin *et al.*, 1993; AI-Janobi *et al.*, 1997). Dong and Kyeong (1997) used a slip ring based technique to measure the axle torque requirement of different agricultural operations in which strain gauges have been mounted on axle shaft. To measure the effect of change in dynamic wheel load on overall performance of an off-road vehicle accurately, it is necessary to measure the soil reaction directly on the drive axle for analyzing the correlations between the dynamic wheel load and the wheel-soil contact forces as well as the wheel slip. An instrumented hub has been developed by Gobbi *et al.* (2005) to measure all three forces and three moments acting on a wheel, in order to characterize the front and rear tractor tires both on road and off road condition. Wolffenbuttel and Foerster (1990) performed a torque sensing by using a strain gauges connected to the axle with slip rings to enable the electrical contacts. A non-contact method was also used for measurement of axle torque based on: (i) optical sensor, (ii) magnetic sensor, and (iii) capacitive sensor; capacitive sensor were prefers over the others for its accuracy. The capacitive torque sensor is basically a differential angular displacement sensor and is composed of two capacitive displacement sensors mounted on the axle and spaced a certain distance apart in order to enable the measurement of the twist angle (**Fig. 4**).

A precision wheel torque and weight transducer for agricultural tractors has been developed by Al-Janobi *et al*. (1997). This system replaces the standard wheel centre of an MF 3090 (Massey Ferguson 3090) tractor to a developed wheel torque transducer (**Fig. 5**) to measure the torque and forces acting on the tractor wheel. The wheel torque and weight transducer incorporated three load sensing clevis bolts. Its force measurement on the revolving wheel combined with the measurement of angular position of the wheel by a position transducer (shaft encoder) is used to determine the total horizontal and vertical components of forces. The other method, telemetry is that of actually transmitting the strain gauge signal through the use of radio-frequency transmitters mounted on shaft and picking up the signal by means of a receiver placed nearby (Palmer 1985; Watts and Longstaff 1989; Snyder and Buck 1990).

Kheiralla *et al.* (2003) developed a drive wheel torque transducer for an agricultural tractor. The unit adopts a design having an extension shaft mounted in between the rear wheel axle flange and rear wheel rim of a tractor. Resistance type strain gauges were bonded on the shaft circumferential surfaces into a Wheatstone bridge circuitry for a standard torque measurement configuration. The bridge circuitry on each side of the rear drive axle was interfaced to a data acquisition system on board a tractor via a slip ring at the drive shaft end. Kumar and Tewari (2013) reviewed the axle torque sensing devices for energy utilization of tractor-implement combinations.

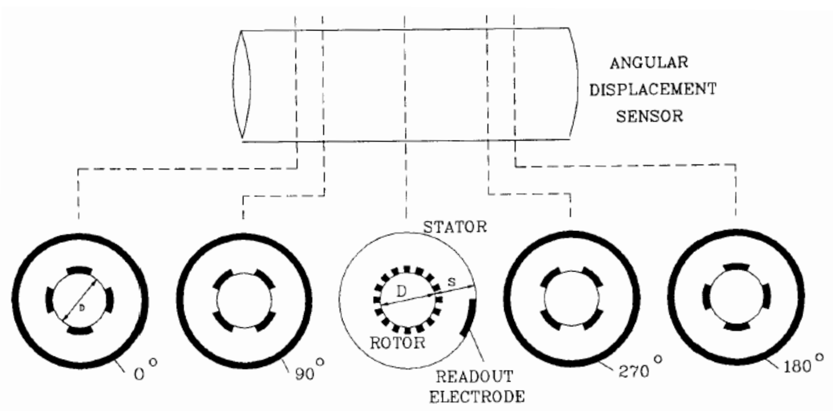

Fig. 4 Capacitive angular displacement sensor for different cross-sections along the axial direction (Wolffenbuttel and Foerster, 1990)

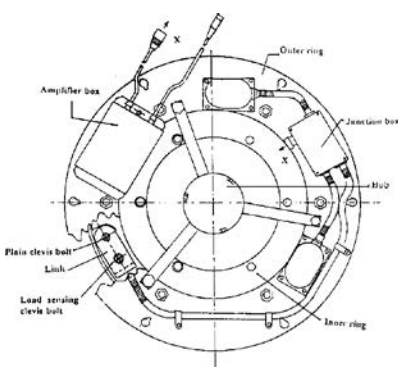

Fig. 5 Wheel torque and weight transducer replaced with the standard wheel centre of the tractor (Al-Janobi *et al.*, 1997)

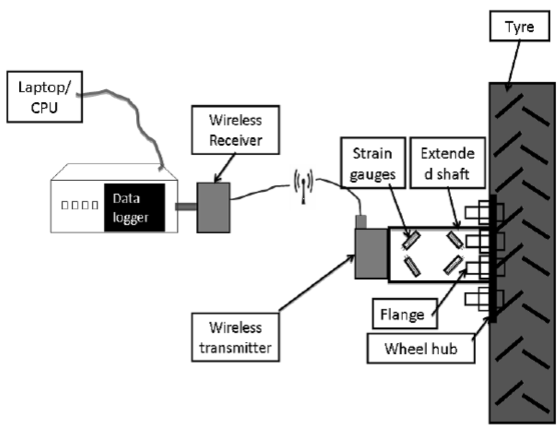

Fig. 6 Interfacing of telemetry system to the strain gauge based axle torque sensor (Kumar and Tewari, 2013)

The review deliberates the latest work being done for tractor rear axle torque measurement systems under dynamic conditions. Also the functional principle of instrumented strain gage based transducers for the farm tractor rear axle was explained to optimize the power requirement of tractor-implement combination. This resulted in suggesting a novel technology for measurement of the dynamic axle torque based on the telemetry interfaced to the strain gauge instrumented transducer. The suggested technology includes the telemetry system in addition to the strain gauge installed extension shaft mounted between the drive wheel rim and drive wheel axle flange (**Fig. 6**).

The detailed advantages and limitations of the listed technologies are briefed in **Table 1** and **2** (See the next page). Further the existing work related to prediction of pulling ability of the tractor is mainly depending on measurement of either draft force or drive wheel axle torque, but the performance of the tractor depends on both parameters in addition to wheel slip.

Telemetry Based Embedded Technology to Increase Operational Efficiencies

Improvement in operational efficiency of tractor cannot be performed by measuring only one parameter. Proper matching of tractor implement combination and maximum energy utilization can be done by measuring both draft and drive wheel torque simultaneously. A novel telemetry based embedded system can be developed to measure draft force, wheel slip and drive wheel axle torque that is illustrated in **Fig. 7a**. To avoid the errors due to lose connection in wire or transferring of the signals from rotating parts, a simple telemetry system is a better option for error free and accurate measurements. Strain gauge instrumented axle torque transducer with telemetry system can be used to measure the drive wheel torque (**Fig. 7b**). A three point hitch dynamometer can be mounted in between implement and tractor to measure the draft force and optical sensors can be mounted near the wheels to measure the wheel slip. Embedded display unit will be mounted near to the operator; it will be visible and within reachable distance from the seat index point (SIP).

An embedded system with a display unit enables the operator to see the availability of the drive torque, draft force obtaining and wheel slippages during operation. It enables the operator to adjust the speed of operation or any other necessary adjustments to improve operational efficiency. Based on the availability of torque, wheel slip and draft force requirement, a farmer can have the choice and flexibility during selection of different sizes of implement and power source.

Conclusions

This study briefs the existing transducers for accurate measurement of draft forces required by tillage implements as well as the tractor drive axle torque. Improvement in operational efficiency, proper matching of tractor-implement and maximum energy utilization can be done by measuring both draft and drive wheel torque simultaneously. A novel telemetry based embedded system can be developed to measure draft force, wheel slip and drive wheel axle torque simultaneously. This may enhance the increased working efficiency, saving of energy, reduced operating cost, increased cost benefit ratio and flexibility of operation. Strain gauge based transducers give the accurate results. A telemetry based embedded system has been recommended over the contact type transmitter-receiver to transmit and receive the signal from the sensor to the data logging system.

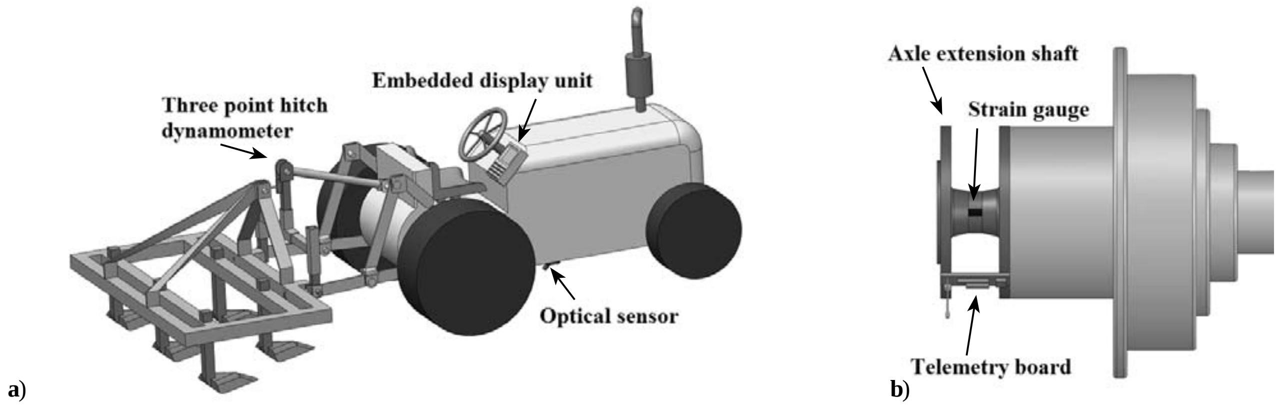

Fig. 7 a) Telemetry based embedded system for measurement of draft and drive wheel torque, **b**) Strain gauge instrumented axle torque transducer with telemetry system

Table 1 Advantages and limitations of draft measurement sensors

Sensors		Advantages	Limitations	References
Strain gauge pins / Drawbar pins		One directional force can be easily measured.	Suitability will be only for free linkage systems. Only measures longitudinal component of force.	Reece, 1961; Zoerb *et al*., 1983.
Linkage type dynamometer	Single extended octagonal rings	Capable of measuring the horizontal force, vertical force and pitch moment. Flexibility of operation relative to tractor	Suitable only to single hitch point conditions. Entire force will act on the single rings	Hoag and Yoerger, 1975; Leonard, 1980; Godwin 1975; O'Dogherty 1975; Godwin et al., 1993; McLaughlin *et al*., 1998; Chen *et al*., 2007.
	Double extended octagonal rings	Capable of measuring the horizontal force, vertical force and pitch moment. Flexibility of operation relative to tractor. Equal distribution of overcoming forces on the octagonal rings	Suitability will be only for single hitch point conditions.	
Strain gauged lower link systems		Strain gauges can be directly mounted on the lower links. Direct measurement of draft forces with less error. Simple and effective system for draft measurement.	Suitability will be only for small to medium type equipment attached to the tractor. Sudden application of forces on links may damage the strain gauges. Effectiveness of the systems depends on the life of mounted strain gauges.	Khan *et al*., 2006.
Adjustable type three point hitch dynamometer		Flexibility of three point hitch attachment, irrespective of implement size. Possible to measure the forces at single and two point hitching conditions.	Limits the implement movement. Sudden jerk or sudden application of forces may cause the damage to the load cell.	Al-jalil *et al*., 2001; Askari *et al*., 2011; Tewari *et al*., 2012.
Chassis type three point hitch dynamometer		Allows the simultaneous use of P.T.O and drawbar. Measures the drawbar forces along with vertical force acting on lower links.	Limits the flexibility while selecting the implements.	Alimardani et al., 2008.

Table 2 Advantages and limitations of torque measurement sensors

Sensors	Advantages	Limitations	References
Slip rings/Coir brush	Direct mounting of the strain gauges on axle shaft. Accurate and précised measurement of the torque coming on axle shaft.	Heat generation within the instrumented system during operation. Wear out of slip rings and loss of sensitivity after particular period of time. Transmission of the signals through wires may leads to loss of sensitivity.	Tompkins and Wilhelm 1982; Wolffenbuttel and Foerster, 1990; McLaughlin *et al*., 1993; AI-Janobi *et al*., 1997; Dong and Kyeong, 1997.
Instrumented wheel hub	Measurement of forces and momentum from all the direction acting on the wheel, both in on-road and off-road conditions.	Variation in measured readings at higher vibrations.	Gobbi *et al*., 2005.
Precision wheel torque and weight transducer	Simultaneous measurement of the torque and forces acting on the tractor dynamic wheel. Telemetry based wireless transmission system.	Requires high maintenance.	Al-Janobi *et al*., 1997
Drive wheel torque transducer	Improved design for measurement of axle torque. Telemetry based wireless transmission system.	Needs to adjust the track width of the tractor. May not be suitable for narrow spaced track widths.	Kheiralla *et al*., 2003; Kumar and Tewari, 2013

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ABSTRACTS

The ABSTRACTS pages is to introduce the abstracts of the article which cannot be published in whole contents owing to the limited publication space and so many contributions to AMA. The readers who wish to know the contents of the article more in detail are kindly requested to contact the authors.

1444

Status of Draught Animal Power Availability in Selected Villages of West Sikkim in India: R. K. Tiwari, Research Engineer, AICRP on UAE, The College of Agricultural Engineering and Post Harvest Technology (CAEPHT), Ranipool- Sikkim, INDIA, rk96tiwari@gmail.com; **S. K. Chauhan**, Asst. Agril. Engineer, same, chauhansujeetkumar@gmail.com

Two billion people in the developing countries depend on draught animal power for farming and rural transportation. Draught power is critically short at the time of crop planting and is insufficient for other purposes throughout the year. Draught power will remain a major source of energy in agriculture into the foreseeable future, and the lack of draught power in some places may be the primary constraint to increasing crop production. Animal draught power was the first supplement to human energy inputs in agriculture. Mechanized power has been used in agriculture only in the last century or so. In Asia, a greater proportion of farmers depend on animals for draught power than in any other parts of the world. A large proportion of these animals belong to farmers who have limited resources and cultivate small areas of land. In most parts of Asia, animal power is supplied by bullocks, buffalo and camels. Bullocks will continue to be the common source of farm power, mainly because they are adequate and live on waste residues. In fifty developing countries, which contain half of the total human population of the world, there is a heavy dependence on draught animals as an energy source. These animals are used for agriculture operations in 52% of cultivated areas of the world, as well as for hauling 25 million carts. This situation is likely to continue for at least another fifty years. The work performed annually by these draught animals would require 20 million tonnes of petroleum, valued at US$ 15 billion, if it were performed by motorised vehicles. Presently a pair of animals, on average, can work about 2-3 ha. It has been demonstrated that with proper management, care and use of improved matching implements a pair of animals can work 4-6 ha, thereby minimizing the requirement of additional power from other sources. The five villages (one from each block) in west Sikkim were selected to be the representative having not too sloppy topography and dominated by animal based farming for draught animal power survey including animal shelter, feed and fodder. The farmers in west Sikkim having diversified agriculture (fruits, large cardamom, ginger, paddy, maize, wheat, black gram, mustard and finger millet etc.) utilized different breeds of draught animals (bullocks) and traditional equipment as per the information collected from the farmers. The body weight of bullock varied 219.28-374 kg and purchase price of bullocks pair was Rs. 23,000 (2011-12) in west Sikkim. The average number of land holdings in identified villages were 321 including 230 of marginal and small farmers. The average area dependent on one pair of bullock in west district Sikkim was worked out as 8 ha. The average population of bullocks was found 168 number in the identified villages of west Sikkim. The average custom hiring was 25 days in a year. The size of animal shelter varied from 2.4 × 2.4 × 2 m to 14.7 × 3.75 × 2.15 m in general. The roofs (50%) of galvanized iron sheet were common in the bullock sheds which has no sloppy concrete flooring and open from all four sides. Very few (15%) compost pits and urine disposable channels were available in the selected villages of west Sikkim. The concentrates @ 1 kg/day-bullock was found to be fed. The traditional plough (weight: 12 kg) and harness (weight: 4 kg) were common which were available in unit price of Rs. 800 and Rs. 500 respectively. The average annual use of bullocks in Sikkim was 49 days as the farming was mostly under rainfed condition.

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1503

Mass Modeling Of Celtis Australis (Celtis caucasica Willd) with Some Physical Characteristic: Yeganeh Reza, Department of Mechanical Engineering of Agricultural Machinery, Faculty of Agriculture, Ilam University, P.O. Box 69315-516, Ilam, IRAN, r.yeganeh@ilam.ac.ir; **Ghari Morteza**, same; **Beigzadeh Yasan**, same

Fruits and vegetables with the similar weight and uniform shape are in high demand in terms of market value. Therefore, an awareness of grading fruits and vegetables based on weight is crucial. A part of this research was aimed to present some physical properties of Iranian Celtis australis. In addition, in this study the mass of Iranian Celtis australis variety was predicted with using different physical characteristics in four models includes: Linear, Quadratic, S-curve, and Power. According to the results, all properties considered in the current study were found to be statistically significant at the 1% probability level. The best and the worst models for prediction the mass of Celtis australis were based on diameter characteristic and volume of the Celtis australis with determination coefficients of 0.7941 and 0.6170, respectively. At last, mass model based on diameter characteristic from economical standpoint is recommended.

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1504

An Analysis on Farm Size and Nonparametric Efficiency Measurement for Food Crops in Pakistan: **Hina Fatima**, Fatima Jinnah Women University, Rawalpindi, PhD Student and Head of Economics Depertment, Fatima Jinnah Women University the Mall Rawalpindi, PAKISTAN, hinnafatima@gmail.com; **Nouman Badar**, H no 770, St No 8, Shahzad Town park Road Islamabad, PAKISTAN, noumanbadar390@gmail.com; **Munib Badar**, same, munibbadar@gmail.com

The objective of this study is to evaluate the effect of farm size on productivity and technical efficiency of three major food crops of Pakistan over the time period 1948-2011. In order to assess the technical efficiency of three major food crops i.e. wheat, rice and maize in Pakistan, most widely known Data Envelopment Analysis (DEA) technique is used. The result of the study reveals that 88% inefficiency is observed in case of wheat production. The efficiency result of Maize crop demonstrates a 9% over-utilization of farm size. The mean technical efficiency of rice crop for variable and constant return to scale frontiers are 0.91 and 0.62, respectively. Hence, indicating the signs of productive inefficiency in rice crop too. Consequently, present study suggests that instead of increasing area under food crops, it is the need of the hour to adopt modernized agricultural technique. Moreover, farmers have to equip with new advancement in agriculture and have to create awareness of high yielding seed varieties of food crops.

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1505

Investigation the Effect of Conservation Tillage on Soil Organic Matter (SOM) and Soil Organic Carbon (SOC) (The Review): **Sherwin Amini**, M-Sc. Mechanization Engineering, Student of Khuzestan Ramin Agriculture and Natural Resources University, Khuzestan IRAN; **Mohammad Amin Asoodar,** Professor, Department of Agricultural Machinery and Mechanization Engineering, Khuzestan, Ramin Agriculture and Natural Resources University, Khouzestan, IRAN

Pores and organic matter take a multitude of forms in soil and their characteristics change in space and time following a change in tillage practices as a new "steady state" is approached. Information on the variation with depth (stratification) in the characteristics of pores and organic matter and the rates of changes in these characteristics are vital to interpreting the short- and long-term impacts of the reduction of using conventional tillage on the productivity and hydrology of agricultural soils. This information is also of value in estimating the effect of a reduction in tillage on the sequestration of carbon in agricultural soils. The influence of tillage on bulk density, macro porosity and organic matter content was found to be documented more extensively than the effects on pore size distribution, soil organic matter fractions and their interactions at different soil depths. Many of the reports documenting tillage-induced changes in soil porosity and organic matter were based on measurements at a specific time after initiating the tillage trial. The potential advantages of conservation tillage in organic farming are reduced erosion, greater macro porosity in the soil surface due to larger number of earthworms, more microbial activity and carbon storage, less run-off and leaching of nutrients, reduced fuel use and faster tillage. Conversion from conventional (CT) to no-tillage (NT) resulted in an immediate change in the placement of aboveground crop residue and the reduced fragmentation of the soil matrix may also slow the mineralization of SOC.

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1506

The effect of Conservation Tillage on Crop Yield Production (The Review): **Sherwin Amini**, M-Sc. Mechanization Engineering, Student of Khuzestan Ramin Agriculture and Natural Resources University, Khuzestan IRAN; **Mohammad Amin Asoodar,** Professor, Department of Agricultural Machinery and Mechanization Engineering, Khuzestan, Ramin Agriculture and Natural Resources University, Khouzestan, IRAN

Conservation tillage (CA) systems are gaining increased attention as a way to reduce the water footprint of crops by improving soil water infiltration, increasing soil moisture and reducing runoff and water contamination. The concept of water footprint is defined as the total volume of freshwater used, directly or indirectly, to produce a product or process including the total amount of water required in agriculture for growing crops. About 141 million and 645 thousand hectares of land in the world have been destroyed by erosion because of inappropriate tillage operations. The total amount of 26 billion tons of soil eroded is estimated and about 2 billion tons comes out from Iran. Parallel to the erosion, loss of soil organic matter that occurs on to several factors, farming has become more challenging. Many strategies exist to combat soil degradation through erosion and compaction on agricultural fields. One of these strategies is conservation agriculture (CA). Reduced or no-tillage techniques, together with crop residue management and crop rotation are the pillars of CA. The term reduced tillage covers a range of tillage practices but it never involves inverting the soil. In this way, soil disturbance is minimized and crop residues are left on the soil. Studies in many European countries have

shown that CA can indeed be very effective in combating soil erosion. However, soil and water conservation do not appear as main drivers in farmers' decisions to shift or not to CA. Economic factors tend to be more important, but there are a lot of uncertainties on this domain. Studies show that production costs are mostly reduced, mainly by reduced fuel costs. Although many European studies have investigated the effect of reduced soil tillage on crop yields, a lot of uncertainties still exist. This means that this method such as rummage soil tillage systems are not common in the soil for at least 30 percent crop residue prior to shall be preserved.

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1521

Experiences and Strategies of Using Sugarcane Harvester in The Cauvery Delta: **P. Karthikeyan**, Research Scholar, Dept. of SWCE, AEC&RI, Tamil Nadu Agricultural University (TNAU), Coimbatore –641 003 INDIA; **S. Thangamani**, same; **J. Stephen Arul**, Shree Ambika Sugars Ltd, Kottur, Thiruvidaimarudhur taluk, Thanjavur district –609 804, INDIA, karthikswce@gmail.com; thangamswce@gmail.com

Availability of sugarcane, suitability of plots for mechanical harvesters, men and materials for operation and maintenance, suitable variety, farmer's attitude and cost of operation influence mechanical harvester operations. The experience with thirty cane harvester machines especially in the Cauvery delta since 2008 is discussed in this paper. Suggestions and plans for future based on the past experiences are also discussed.

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1605

Design and Development of Fibre Extractor for Small Sisal Farmers: **R. K. Naik,** Scientist (FMP), ICAR-Central Research Institute for Jute and Allied Fibres, Barrackpore, Kolkata-700120, West Bengal, INDIA, ranjanagrieng@rediffmail.com; **S. C. Pradhan**, Ex-Professor & Head (FMP), College of Agricultural Engineering and Technology, Odisha University of Agriculture & Technology (OUAT), Bhubaneswar-751003, Odisha, INDIA; **R. C. Dash**, Professor (FMP), same; **A. K. Goel**, Associate Professor (FMP), same

Extraction of fibre from sisal leaves is the most critical operation for small sisal farmers. For small-scale sisal fibre extraction, a portable fibre extractor was designed, developed and tested. The fibre extractor provides improved sisal leaf processing with less energy input and reduced cost. It was observed that the throughput capacity and material capacity of the fibre extractor was found to be 330-380 kg leaves/h and 12-14 kg dry fibre/h, respectively with a design efficiency of 50 per cent and average fibre yield of 4 percent/leaf. It was found that maximum fibre extraction efficiency of 96.66% can be achieved by processing the freshly harvested sisal leaves (80-85% moisture content) at a beater cylinder peripheral speed of 10.69 m/s (510.6 rpm) and beater blade clearance of 0.80 mm with fixed knife unit. It was calculated that unit fibre extraction cost per quintal of dry sisal fibre by using developed sisal fibre extractor is Rs. 364.43.

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1606

Operating Characteristics of a Vacuum Pump Used in Milking Machines at Different Vacuum Pressures and Altitudes: **H. Unal**, Univ. of Uludag, Faculty of Agriculture, Dept. of Biosystems Engineering, Bursa, 16059, TURKEY, hunal@uludag.edu.tr; **H. Kuraloglu**, Univ. of Uludag, Graduate School of Natural and Applied Sciences, Bursa, 16059, TURKEY; **S. Arslan**, Univ. of Uludag, Faculty of Agriculture, Dept. of Biosystems Engineering, Bursa, 16059, TURKEY; **H. Erdogan**, same

The objective of this study was to determine the deliverable flow rate of a vacuum pump with a flow rate capacity of 200 l/min as a function of altitude up to of 2,000 m, which was mounted on a portable bucket type milking machine. Maximum pump pressure, air flow rates at operating vacuum range (36-52 kPa), measured vacuum pressure, relative humidity and air temperature were measured every 100 m. Atmospheric pressure decreased by 21.3% at the altitude of 2,000 m compared to the measured 100.2 kPa at the sea level. Maximum pressure of the vacuum pump at altitudes of 500 and 2,000 m reduced by 4.5 and 18.4%, respectively. Similarly, the measured air flow rate of the vacuum pump at the sea level at 50 kPa reduced about 35% at 2,000 m. To see whether other parameters could be determined based on the variations in altitude, regression relations were found for measured pressure–altitude, maximum pump pressure-altitude, air flow rate-altitude, and air flow rate-pump vacuum-altitude. Determination coefficients (R^2) were found to be very high (0.994-0.999) among the relationships evaluated. As a result, all the studied factors could be accurately calculated as a function of altitude. Thus, the necessary settings could be done to correct the performance of the milking machine.

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1609

Linear Quadratic Regulator (LQR) and PID Control of Tank Level of Agricultural Field Sprayer: M. Gunes, Kahramanmaras Sutcu Imam Univ., Faculty of Engineering and Architecture, Dept. of Electrical and Electronics Engineering, Kahramanmaras, 46100, TURKEY, gunesmahit@gmail.com; **E. Bay**, Kahramanmaras Sutcu Imam Univ., Institute of Natural and Applied Sciences, Dept. of Electrical and Electronics Engineering, Kahramanmaras, 46100, TURKEY, **S. Arslan**, Uludag University, Faculty of Agriculture, Dept. of Biosystems Engineering, Bursa, 16059, TURKEY

The purpose of this paper was to do theoretical analyses to improve the dynamic response of the level and mixing rate control of the mixing tank used on a field sprayer. Block diagrams were developed for tank level control and injection (mixing) rate control. Block diagrams for the mixing tank level consisted of both PID and Linear Quadratic Regulator (LQR) controllers. To do the simulations, the model was linearized and then PID and LQR methods were applied using Matlab-Simulink program. As a result of testing the developed mathematical model, it was found that PID control had about 6% overshoot whereas LQR had no overshoot in a response to unit step input. Furthermore, LQR resulted in much faster dynamic response compared to PID control. Therefore, it was concluded that LQR controller was more appropriate for controlling the chemical mixture rate in the mixture tank of an agricultural field sprayer.

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1616

Improved Potato Diggers in Terrace Condition of Sikkim in India: R. K. Tiwari, Research Engineer, AICRP on Utilization of Animal Energy, The College of Agricultural Engineering and Post Harvest Technology (CAEPHT), Ranipool, Sikkim, INDIA, rk96tiwari@gmail.com; **S. K. Chauhan**, Assistant Agril. Engineer, same, chauhansujeetkumar@gmail.com

Potato digging with improved diggers having high effective field capacities and higher digging efficiency was carried out, ensuring total losses within permissible limit. Light weight, single row animal drawn improved digger was developed and evaluated in terraces for harvesting tubers. The performance of the digger was also compared with power tiller mounted digger and traditional digging methods prevailing in the region.

Light weight animal drawn potato digger was tested at average speed of 1.72 km/h at 120 mm depth of operation. Digging efficiency and field efficiency were 93% and 88% respectively. Effective field capacity and cost of operation were 0.030 ha/h and Rs 1,250/ha. Labour requirement was 34 man-h/ha excluding 150 h for picking of potato after harvest which showed a saving of 38.25% in labour and 60.93% in cost of digging (including picking of potato) over traditional digging by *kudal*/spade in terraces. Physical damage to dug out tuber was about 1% as compared to 4.6% in power tiller mounted digger and 0.8% in manual digging. Effective field capacity of power tiller mounted potato digger of 300 mm size was 0.055 ha/h and its field efficiency and digging efficiency were 82% and 89.8% respectively. The cost of operation with improved digger was Rs 1,250/ha as compared to Rs 3,200/ha by manual method and Rs 1,875/ha using power tiller mounted digger.

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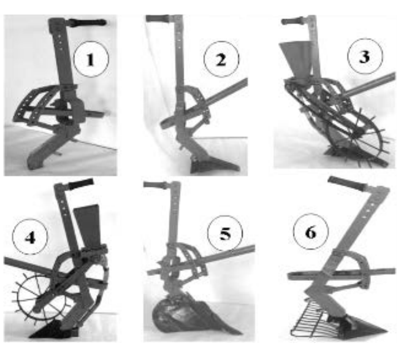
1618

Field Performance Evaluation of Pant-ICAR Animal Drawn Six-in-One Tillage Outfit in Kumaon Hills of Uttarakhand: Sukhbir Singh, Senior Scientist, Division of Agril. Engineering, ICAR-IISR., Lucknow-226002, INDIA, srsukhbir@rediffmail.com; **D. C. Sahoo**, Senior Scientist, ICAR-IISWC, Research Centre, Sunabeda, Koraput- 763 002 (Orissa), INDIA; **N. K. Singh**, SMS, KVK, ICAR-VPKAS, Bageshwar -263 628 (Uttarakhand), INDIA; **J. K. Bisht**, Principal Scientist and Head, Crop Production Division, ICAR-VPKAS, Almora-263601, INDIA; **T. C. Thakur**, ICAR National Professor, GBPUAT, Pantnagar- 263145, INDIA



Pant-ICAR Six-in-one Animal Drawn Tillage Outfit
(1) Tillage Outfit, (2) Jet Plough, (3) Deep Fertilizer Applicator, (4) Seed Drill, (5) Ridger/Furrower (6) Root Crops Digger (also used for interculture by mounting sweeps only)

In hill agriculture, bullocks are mainly used for ploughing with traditional wooden *hal* and puddling with *mai* for not more than 30-40 days in a year. These age-old tools and implements are not only consuming more time and labour full of drudgery but also incur higher cost of operation. The local hill plough called '*hal*' used by most of the farmers is made of *Banjh/Utish* wood which needs frequent replacement of different parts with life span of 4 to 5 years. To overcome these problems, a scientifically designed 'Six-in-one tillage outfit' made of steel was developed and patented under the ICAR National Professor Scheme at Pantnagar. The feasibility trials of this outfit when working as a Jet plough, Fertilizer applicator, Seed drill, Ridger and Potato digger were conducted at ICAR-VPKAS, Almora experimental farm as well as at farmers' field during 2012-13. The field capacity of Jet plough, Seed drill, Ridger and Potato digger was found to be 0.02, 0.035, 0.05 and 0.042 ha/h, respectively. In case of ploughing with Jet plough an average draft of 0.55 kN was observed with soil inversion of 26.4% as most of the residues were retained at the surface. The highest yield of wheat (6.14 t/ha) was obtained when fertilizer was placed at 5-10 cm depth with fertilizer applicator of outfit before sowing. The ridger and potato digger were found feasible to be used manually in small plots. The 'Pant-ICAR animal drawn six-in-one tillage outfit' was recommended to hill farmers for enhanced annual utilization of bullocks in different agricultural operations.

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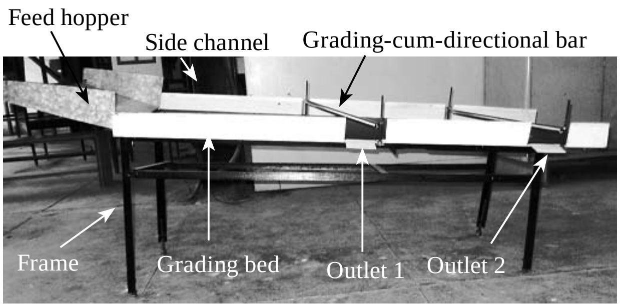
1620

Development of a Low Cost Small Scale Fruit and Vegetable Grader: Satish Kumar, Professor, Deptt. Of Processing & Food Engineering, Punjab Agricultural University, Ludhiana-141004, Punjab, INDIA, satish66@pau.edu; **Sandhya**, Assistant Research Engineer, same, sandhya-pfe@pau.edu; **Mahesh Kumar**, Professor, same, mahesh@pau.edu; **Akshit Puri**, Student, same, **Vishavdeep Kaur**, same



Fruit and vegetable grader

A low cost, small scale and portable grader for small and marginal farmers using a grading bed and three step grading system has been developed and tested for aonla, chiku, guava and lemon. Overall dimensions of the grading machine were 150 × 50 × 60 cm. Longitudinal and transversal slope of grading bed was 5±1 and 3±1 degrees for aonla, chiku, guava and lemon. Capacity of machine for aonla, chiku, guava and lemon was 95, 80, 120 and 98 kg/h respectively. Percentage of fruits collected at desired outlets was 85.8, 83.0, 90.7 and 88.0; while percentage of fruits blocked were 14.2, 17.0, 9.3 and 12.0 for aonla, chiku, guava and lemon respectively. Weight of the machine was 21 kg and cost was Rs 3250 (52.42 US dollar). Overall it is a low cost and portable grading machine for round fruits and vegetables. The efficiency was found to be 88.0, 90.7, 87.0 and 83.0% for lemon, guava, aonla and chiku respectively.

■■

1621

Design And Development Of A Multi-Crop Manual Seed Drill: T. Rani Sarker, Lecturer, Dept. of Farm Power & Machinery, Bangladesh Agricultural University, Mymensingh 2202, BANGLADESH, tumpasarker18@gmail.com; **M. Alam**, Professor, same, murshedalam@gmail.com; **M. A. Haque**, same, ashrafulha@yahoo.com; **C. K. Saha**, same, cksahabau@gmail.com

A machine which can sow seeds of paddy, wheat, black gram, mung bean, lentil, mustard, and radish in rows was designed and developed at the department of Farm Power and Machinery, Bangladesh Agricultural University. The machine was consisted of two wheels, two drums with a number of peripheral openings in seven rows, furrow opener, furrow closer and handle. There was a provision to change the openings of drum for different types of seed and row spacing for sowing seeds. The average seed rate was found 88 kg/ha, 122 kg/ha, 33 kg/ha, 50 kg/ha, 32 kg/ha, 3.8 kg/ha, and 7.2 kg/ha for paddy, wheat, black gram, mung bean, lentil, radish, and mustard, respectively at normal walking speed. A relation was found between seed rates and filling condition of drums. Since the seed rates were not uniform with the change of filling conditions of drums by seeds, agitators were designed and fixed with the shaft to get the better seed rate at different filling conditions. The best filling conditions of drum to get the uniform seed rate were found to be 0.9-2 kg, 0.25-1.7 kg, 0.8-2 kg, 1.4-2.2 kg, 0.9-2 kg, 1-1.21 kg and 1-2 kg for paddy, wheat, black gram, mung bean, radish, mustard, and lentil, respectively whereas the best operational speed of the machine was found 2-4 km/hr. The average effective field capacities of the machine at a speed of 2.58 km/hr were 0.17 ha/hr (width 80 cm), and 0.24 ha/hr (width 120 cm) having field efficiencies as 82.22% and 78.6%, respectively. The estimated cost of the machine was $75 only. The weight of the whole machine was only 14 kg and required a pulling force of only 10.5 Kg which made it to operate at ease by a man or a woman in the field. Overall performance of the multi-crop seed drill machine was found satisfactory.

■■

1623

Small Mechanization Big Benefits: Farmers Willingness to Pay for the Two Wheel Tractor in the Hilly Areas of Pakistan: Akhter Ali, Agricultural Economist, International Maize and Wheat Improvement Center (CIMMYT), CSI Complex, Park Road, Islamabad, PAKISTAN, akhter.ali@cgiar.org; **Imtiaz Hussain**, Cropping System Agronomist, same; **Muhammad Imtiaz**, Country Liaison Officer, same

In Pakistan currently there are no two wheel tractors operational in farmer fields. The current study was carried out in the hilly areas of Gilgit-Baltistan (GB) and Azad Jammu and Kashmir (AJK) to assess the availability and suitability of TWT for farm operation in these areas. In some parts of the hilly areas the four wheel tractor cannot be used for ploughing land due to topography and thus farmers still use bullock and the hand implements for land preparation. During this study data were collected from the farmers by using a comprehensive questionnaire. The difference in the key characteristics of the farmers willing to pay for the two wheel tractor and not willing to pay for the two wheel tractor indicated that farmer having higher education, secured land rights and higher household assets are normally willing to pay more for the two wheel tractors. The farmers were willing to pay more for the imported tractors as compared to the local manufactured tractors if the option become available. The farmers were willing to pay more for the two wheel tractors if the implements can be drawn with the two wheel tractor and vice versa. For the affordability and sustainability the local production of the two wheel tractors should be encouraged which can ensure the lower prices and large scale use. One approach could be the provision of initially subsidy from the government side which can help to popularize the two wheel tractor especially in the hilly areas of Pakistan where four wheel tractor did not become very successful as well as popular like plains areas.

■■

EVENT CALENDAR

2018

◆ **GlobalG.A.P. Summit 2018**
November 5-7, Lima, PERU
http://www.summit2018.org/

◆ **EIMA 2018**
November 7-11, Bologna, ITALY
https://www.eima.it/en/index.php

◆ **EuroTier**
November 13-16, Hanover, GERMANY
https://www.eurotier.com/

◆ **21st FOODAGRO Africa 2018**
November 22-24, Dar-es-Salaam, TANZANIA
https://expogr.com/tanzania/foodexpo/index.php

◆ **Nebraska Power Farming Show**
December 4-6, Nebraska, USA
https://nebraskapowershow.com/

◆ **FIRA—International Forum of Agricultural Robotics—**
December 11-12, Toulouse, FRANCE
https://www.fira-agtech.com/

2019

◆ **3rd Rendez-Vous Techniques AXEMA**
February 23, Paris, FRANCE
https://cloud.agoraevent.fr/Site/144103/4647/Event

◆ **SIMA**
February 24-28, Paris, FRANCE
https://en.simaonline.com/

◆ **World Agri-tech Innovation Summit**
March 19-20, San Francisco, USA
https://worldagritechusa.com/

◆ **HortEx Vietnam 2019**
March 13-15, Ho Chi Minh City, VIETNAM
https://www.hortex-vietnam.com/

◆ **3rd International VDI Conference—Smart Farming 2019**
May 14-15, Düsseldorf, GERMANY
https://www.vdi-wissensforum.de/en/event/smart-farming/

◆ **XXXVII CIOSTA & CIGR Section V International Conference**
June 24-26, Rhodes, GREECE
http://ciosta2019.com/

◆ **2019 EFITA International Conference**
June 27-29, Rhodes, GREECE
http://efita2019.com/

◆ **ASABE 2019 Annual International Meeting**
July 7-10, Massachusetts, USA
https://www.asabe.org/Event-Detail/2019-annual-international-meeting

◆ **ASIA AGRI-TECH EXPO & FORUM**
October 31-November 2, Taipei, TAIWAN
https://www.agritechtaiwan.com/en-us/

◆ **Agritechnica**
November 10-16, Hanover, GERMANY
https://www.agritechnica.com/en/

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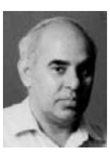
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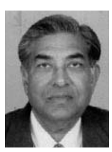
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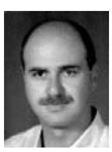
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AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA

(Vol.48, No.1, Winter, 2017-)

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e. have a 50 to 100-word abstract, preferably preceding the main body of the article;
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i. Express measurements in the metric system and crop yields in metric tons per hectare (t/ha) and smaller units in kilogram or gram (kg/plot or g/row).
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k. Convert national currencies **in US dollars** and use the later consistently.
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