Irrigated and Mechanized Cotton Production

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Abstract Cotton holds a unique position in Ethiopia's agrarian economy. Ethiopia has enormous potential for cotton production. Ethiopia has favorable weather and topography for cotton cultivation and production. Cotton (*Gossypium hirsutum* L.) is currently widely grown in irrigated lowlands on large-scale farms and in warmer mid-altitudes on small-scale farms under rainfed conditions. According to a recent Ministry of Agriculture study, there is 3,000,810 Ha of land suitable for cotton production, whereas it is currently limited to a maximum of 100,000 ha. Cotton demand is expected to remain strong in Ethiopia, and there is a clear need to improve productivity in future to meet this rising demand. Ethiopian cotton production is hampered by low productivity caused by 40% and 60% rainfed and irrigated cultivation, respectively. Following that was a small farm size, an increase in pest and disease, and a labor-intensive method of cotton cultivation. Because labor costs are rapidly rising in Ethiopia, mechanization in cotton cultivation will be critical in keeping costs under control. Furthermore, high-density planting will increase productivity. However, high-density planting in conjunction with mechanization necessitates the development of sympodial cotton hybrids as well as a complete transformation in agronomy practices.

Keywords Mechanization · Middle Awash · Tendaho · Setit-Humera · Irrigation · Drip irrigation

1 Introduction

Cotton (*Gossypium hirsutum* L.) grown in Ethiopia is also the primary raw material for the international textile industry, the most valuable natural fiber, and the world's second largest oil-seed crop [1, 2]. This cotton needs irrigation for the following main reasons:

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(1) To provide a more consistent yield from year to year.
(2) To protect the crop's yield potential—being short 25.4 mm of water at the wrong time can easily result in the loss of 34 kg of seed and 23 kg of fiber.

Irrigation benefits both the producer and society by increasing yield per unit of land area and by providing a consistent and dependable source of food and fiber. Irrigation protects crops from poor crop performance and/or failure caused by insufficient and/or untimely rainfall. In today's competitive markets, where significant investment has been committed at cotton planting time, protecting against rainfall uncertainties is highly desirable. Irrigation also makes agro-chemical management easier by allowing for the use of fertigation and chemigation practices.

It is estimated that approximately 70% of the world's freshwater consumption is for irrigation (all crops, not just cotton), and for good reason. Irrigation can increase yield as well as stabilize yield and quality by ensuring adequate soil water throughout the growing season, or at least during critical growth stages in areas where water resources are limited.

Reference [3] discovered that when dry conditions existed, cotton had a linear relationship with irrigation level. Furthermore, they reported a significant response even in a dry year,however, the relationship was quadratic rather than linear, indicating a decreased response at higher irrigation application rates. Reference [4] discovered a significant increase in cotton lint yields in response to irrigation. They reported that providing low levels of irrigation increased yields by nearly 91 kg per 4046.86 m^2 when compared to dry-land. However, they found no benefit from high levels of irrigation. As a result, properly managed irrigated mechanized cotton farming is a critical activity required for success in today's global competitive marketing system. Mechanization in cotton cultivation was nearly completed 20 years ago, from soil preparation for planting to the stage just before harvesting. Of course, there have been advancements since then as a result of new technology in this field.

Mechanical harvesting began experimentally with pickers and strippers in 1963, but there were numerous challenges to overcome, including very small agricultural holdings, land partitioning (fragmentation), high machinery costs, and so on. Cotton pickers were first used in a significant amount in 1972–73.

2 History of Mechanized Cotton Production in Ethiopia

The process of agricultural mechanization necessitates the gradual introduction of capital into the production function. Essentially, the agricultural production function combines land, labor, and capital under the supervision of the framer acting as manager. The nature of changes in the production function is determined by the intended function of the newly introduced capital. Capital invested in labor-saving equipment becomes a substitute for labor and is considered a labor-saving technological change. Conversely, agricultural equipment that improves cultivation without displacing labor becomes a substitute for land, resulting in a land-saving technological change. A change involving capital as a substitute for neither land nor labor is a neutral technological change. This latter type of change has the potential to boost the productivity of all factors.

Understanding the effects of mechanization and the possibilities for successfully implementing such changes necessitates a thorough description of the farming systems into which the changes of mechanization may be introduced.

Hand tool and draught animal power mechanization were the main methods of cotton production in Ethiopia during the Emperors' period (except for some mechanized farms such as the Middle Awash, Tendaho, and Setit-Humera). Cotton production of this type was widespread during the so-called "Derg," a socialist regime that ruled from 1974 to 1991. During this period, the socialist command economy was followed by the Land Proclamation of 1975, and acknowledging the importance of large-scale mechanization, the socialist regime established large mechanized (third category) farms, then known as "State farms," by confiscating private farms and establishing new ones [5].

2.1 The Middle Awash Mechanized Cotton Production

The Middle Awash mechanized cotton production scheme was based on irrigated cotton technology and was implemented prior to the "Derge" regime in 1969. The total area on the Amibara Plaines was 12,000 hectares. The scheme was intended to gradually introduce regime settlers to the complexities of mechanical power agricultural production to large-scale cotton production. The Middle Awash Settlement scheme's goal was primarily technical, with sociological implications. It was founded on the technology of irrigated cotton cultivation. The goal of growing cotton on land previously grazed by pastoralist herds was to encourage a number of these people to settle and become sedentary farmers [6].

There were several major factors that favored the settlement's success. The area is sparsely populated and undeveloped, aside from being a traditional grazing area for Afar herds and flocks. The scheme's goal is to settle nomadic people in a more prosperous way of life in an area where social pressures are increasingly hostile to nomadic traditional life. Economically, the scheme was based on cotton production in a relatively fertile region of a country with a high internal demand for cotton. There is also the huge benefit of being close to the Melka Werer Research Station. The station was established several years prior to the 1964 settlement and has experimental experience from which local farming enterprises can benefit.

2.2 The Tendaho Mechanized Cotton Production

The Tendaho Plantation Share Company was formed as a joint venture between Imperial Ethiopian Government agencies, Ethiopian shareholders, and Mitchell Cotts and Company with a share capital of $2,472,000 dollars. It is an example of a large-scale commercial plantation. The entire land concession in the Danakil Desert covers 10,000 hectares, and the plantation covered 5,500 hectares in 1968/69. During that cultivation stage, this case represents a highly mechanized operation, with hand labor reaching a peak of 7,000 workers at the peak of the raw cotton-picking season in November. For the 1968/69 season, 90,000 quintals of cotton were estimated, with ginned cotton sold in the domestic market and cotton seed primarily exported. In 1968/69, the estimated budget production costs of $366,830 would be paid out in day laborer wages. Export potential is critical, especially because Tendaho was producing high-quality cotton that competed in the world market at the time [7]. Tendaho plantation demonstrated intensive and efficient management capabilities and was one of the most successful private commercial enterprises at the time.

During its initial development and growth from 500 to 4,000 hectares in size, the Tendaho plantation required 55–60 hp. tractor for every 11 hectares under cultivation. Since expanding to over 5,000 hectares, the managers have been able to increase the amount cultivated per tractor to 150–160 hectares due to increased field efficiency, better operators, more level fields, fewer vet spots, and less breakage and downtime. At least half of this increase in efficiency can be attributed to improved training and experience among tractor operators who take on more responsibility for their equipment.

2.3 Machine Field Efficiency

Records showing work rates and average field capacities for various field operations from 1966 to 1968 are particularly revealing. Recognition of the importance of tractor operator training, recognition, and experience contributed to part of the indicated increase in efficiency. Table 1 displays data on the efficiency of field operations. Unless otherwise specified, all of the machines in the table are powered by a 58 hp. Massey Ferguson 165 tractor or equivalent.

The Massey Ferguson 165 (MF165) (Fig. 1) is a row-crop tractor that was manufactured in Massey Ferguson's Detroit, Michigan plant from 1964 until 1975. It, like the MF135, was a popular tractor on the market at the time.

The MF165 was available with one of four engines: the 3.3-L Perkins diesel engine, the 2.9-L Continental gasoline engine, the 3.5-L Perkins diesel engine, or the 3.5-L Perkins gasoline engine. Each of the four engines has four cylinders as well as liquid cooling. The bore/stroke of the 3.3-L Perkins is 91 × 127 mm, while the 2.9-L Continental is 91 × 111 mm, and both 3.5-L Perkins are 98 × 114 mm. Each of the four engines can produce 58.3 horsepower. It can hold 70 L of fuel. This

Table 1 Comparative efficiency of field operations: Tendaho Plantations Share Company 1966–1968

Field operation	Machine	Time period (hrs.)	Capacity (hectares)		
			1966	1997	1968
Plowing (2 cm)	4-furrow disk plow, mtd	10	2–3	4	4–5[a]
	5-furrow moldboard plow	10	-[d]	-[d]	6–8[a]
Harrowing	No. 52 Tandem, 3-m cut	10	8	20	20–25
Disking	M-36 wide -level, one way (24 disk)	10	10	25	30–35
Planting	4-row unit planter, (91 cm. rows, no fertilizing or spraying)	12	8	14	20–25
	6-raw planter (made from 1 1/2, 4-raw machines)	12	-[d]	-[d]	35[b]
Inter-row cultivation	3-row rear-mtd. rigid-tooth cultivators	8	6	16	16[c]
	4-row mid and rear-mtd. spring-tooth cultivators	8	8	20	20[c]
Slashing	182 cm. rotary single–blade	10	5	7–10	15
	3-m rotary double-blade	10	d	20	25
Leveling	3 m Eve-son land plane	10	-[e]	-[e]	-[e]
Hauling	2.5 × 3.0 × 2.5-m high bulk trailers (crop put in bags in field)	8	-[f]	-[f]	-[f]

[a] With 10 plows, 50 ha./day during the 1968 season were averaged. The HF-175 tractor was used with the 5-furrow moldboard plow
[b] With an experienced driver and an assistant to watch the planters, up to 48 ha. has been planted in one 12-h day
[c] Because of the good, straight, and even job of planting, 3-row cultivators in fields planted with 4-row planters, and also 4-row cultivators in fields planted with 6-row planters were used
[d] Not in use at that time
[e] Variable—depends on field condition and unevenness
[f] Variable—depends on distance and road conditions
Source Kline et al. [6]

tractor has a 4 × 2 two-wheel drive chassis. It features power steering, mechanical dry disc brakes, and an open operator station. In terms of transmission, the MF165 was available with one of three options: a 12-speed partial power shift, a 6-speed, or an 8-speed.

Reduced tillage systems will allow farmers to use smaller tractors for longer periods of time and with fewer repairs as cotton farms are mechanized. Aside from lower maintenance and repair costs, smaller horsepower and longer operating time of tractors imply lower total tractor cost per hour, and thus lower production costs. Estimating the relationship between various tractor cost variables (age, horsepower,

Fig. 1 Massey Ferguson 165 Tractor. *Source* https://gwtractors.com.au/massey-ferguson-165-tractor/#:~:text=Part%20of%20the%20100%20Series,the%20market%20during%20its%20time

repair cost, total cost per hour) is a critical activity that must be completed prior to the implementation of mechanized cotton farms.

2.4 The Setit-Humera Mechanized Cotton Production

In 1954, mechanized farming began in the northwest Ethiopia lowlands. It was started on the initiative of private entrepreneurs and has since been developed by them. The government's role has been limited to the allocation of land to farmers and the general administration of the area. Early development was slow, but between 1963 and 1968, there was rapid growth. By 1968, over 400 tractors were in use, and approximately 100,000 ha of land had been planted. Despite poor communications and a general lack of facilities, tractor dealers have either set up workshops or appointed dealers to stock fast-moving spares at Setit-Humera, and the service and spares situation for farm tractors was satisfactory.

The farming system was extensive, with low inputs and outputs per unit of land. Many farmers and their laborers come from cities and neighboring highland areas, and they only live on the farms during the crop season. Farmers use modern tractor-drawn equipment to cultivate and plant large areas at low cost, but weeding and harvesting are not automated. Fertilizers and pesticides were not used, despite the fact that cotton pests were becoming more of a problem as the area under cotton cultivation expanded. Economic responses to fertilizer were achieved as yields increased through the use of improved machinery, better weeding, and new varieties.

The estimated yield was 300 kg/ha. Cotton seed was ginned in Asmara (480 km from Setit-Humera). The Government owned the land in mechanized farming, and occupiers were assigned land by the Governor of the Woreda (District) through an annual permit system. However, no titles or leases have been issued, and the only condition of occupation is that the occupier agrees to pay education and health taxes. As a result, farmers' rights to the land were not defined, there was no incentive for them to invest in long-term improvements, and land could not be used as collateral for the credit most farmers require to carry out improvements. The government was aware of the issue and was informed during negotiations that satisfactory arrangements for the grant of long-term leases to farmers would be required for any lending for a second-stage project. (International Bank for Reconstruction and Development, International development association, Humera agricultural development project, Ethiopia, 1970).

3 Mechanization Status on Cotton Crop

Cotton is an important commodity in Ethiopian agriculture, and it has played an important role in Ethiopia's cultural and industrial development history. To comprehend Ethiopia's future role in domestic and international cotton markets, a better understanding of its cotton production system is required. Despite the fact that Ethiopia is Africa's second largest cotton consumer, cotton production productivity is very low when compared to the global average. It is a major concern for policymakers because the cotton sector is important in both social and economic aspects of Ethiopian society. The existence of lower-than-world-average yields in Ethiopia has been attributed to a variety of factors, including insufficient inputs, a lack of awareness about modern cotton cultivation practices among Ethiopian farmers, limited irrigation facilities, a lack of proper timing of field operations, and an overreliance on labor to cultivate cotton. Along with the aforementioned factors, a labor shortage in some large-scale farming areas of Ethiopia where picking and weeding are done by hand is reducing cotton crop profitability. In this context, a better understanding of Ethiopia's cotton sector and the impact of mechanization on cotton cultivation is required to assess Ethiopia's competitive position in the international market.

Cotton harvesting mechanization is dependent not only on the availability of suitable harvesters but also on the availability of appropriate cotton varieties, changes in agronomic practices such as seed rate, nutrient application, and so on, and finally on its economic feasibility in Ethiopia. No other African country has the same potential as Ethiopia to grow a diverse range of cotton varieties using rainfed or irrigated systems, cotton cultivation in various agro-climatic zones. Paradoxically, one single variety (DP 90) is currently grown on more than 90% of cotton cultivation areas, despite the fact that seed quality is poor and ginning outturn (GOT) is low by African standards, affecting profitability for both producers and ginners [4].

Farmers in many parts of Ethiopia still use human labor for many operations such as planting, weeding, and picking, as well as inefficient farm implements/machinery. Machinery adoption in farm operations is lagging due to a variety of factors such as a lack of credit to purchase expensive machinery, farmers' small land holdings (generally less than 1 ha), and a lack of technical knowledge and skills to operate complex farm machinery. The persistent low yields in Ethiopian cotton production are also attributed to a scarcity of disease-resistant and high-yielding cotton varieties.

Recently, in Ethiopia, a variety of cotton production systems coexist under irrigation (26% of total cotton cultivation area) or rainfed conditions, ranging from very large farms developed by investors (more than 200 ha of cotton) to very small family farms (generally less than 1 ha). The large-scale farms, not the small ones, are heavily mechanized (Fig. 2). Weeding and harvesting are still done by hand and require a lot of effort. In comparison to major African countries, average seed cotton yields are relatively high, at 2.5 tons/ha with irrigation and 1.5 tons/ha with rainfed conditions. The global average is 2.6 tons/ha (FAO production yearbook 2020). Large-scale farms are frequently established with the funds of investors whose goal is to make good and quick profits and returns. Prior investments were made with a view to short-term profitability (field preparation, machines, management), and the cropping system in place is not environmentally friendly or sustainable. Few temporary shelters or roads, wide open fields with rare trees, intensive plowing, and mono-cropping do not ensure the long-term sustainability of most of these farms (Fig. 3).

Fig. 2 Mechanized farm in the Afar region. *Source* Lançon and Woldu [8]

Fig. 3 Large-scale farms with open fields in the rainfed areas, Setit-Humera region. The crop has been broadcast. *Source* Lançon and Woldu [8]

3.1 Precision Agriculture Adaption to Mechanized Cotton Farms

Precision Agriculture (PA) is a management strategy that allows farmers to adjust input use and cultivation practices to match within-field variability in soil and crop conditions [9]. This ensures that the inputs are only applied at the required rates at various parts of the field with varying nutrient content and crop requirements. As a result, precision agriculture improves input use efficiency while lowering the potential negative environmental impact of agricultural chemical overuse [10]. In terms of input management, PA assists producers in making more informed management decisions, and site-specific knowledge allows producers to limit input use in accordance with the crop's spatial and temporal requirements [11].

Modern technological advances, such as Global Positioning Systems (GPS) and Geographical Information Systems (GIS), have added a new dimension to the practice of PA. Most researchers now regard PA as a system comprised of various components such as auto steering technology for tractors, automatic section control for sprayers and planters, geo-referenced soil sampling, various methods of soil variability analysis, and variable rate input application. However, in the traditional sense, PA entails collecting within-field variability data, processing this variability data to assess the extent and distribution of variability, and, if necessary, responding to this variability variable rate application of inputs to match the variability [12]. Common variability detection practices include using yield monitors, soil maps, geo-referenced soil grid and zone sampling, aerial photos, or satellite imagery to identify variability in soil fertility, pH of the soil, crop vigor, or moisture stress. Once the variability within the field has been detected and analyzed, the information is used to apply inputs such as fertilizers, lime, pix, or irrigation water in such a way that each portion of the field receives the input in the required quantities. Adopting PA strategies is important not only for increasing farm profitability and sustainability but also for protecting the environment because the inputs are not applied in excessive quantities, limiting the potential leaching of chemicals into water streams.

3.2 Irrigation Adaption to Mechanized Cotton Farms

Cotton (*Gossypium hirsutum L.)* is the primary raw material for the international textile industry, the most valuable natural fiber, and the world's second largest oil-seed crop [1, 2]. Cotton yield is influenced by a variety of factors including edaphoclimatic constraints, genotypes, and crop management practices. Cotton cultivation is primarily rainfed in the majority of the world's producing regions, including Ethiopia. Rainfed cotton cultivation accounts for 74% of cotton cultivation in Ethiopia. Because of the high crop water demand (Fig. 4), the water deficit caused by semi-arid region droughts is the primary factor limiting high yields.

Irrigation is critical to ensuring the sustainability of production in water-stressed areas, particularly when combined with efficient water consumption and economic viability [9, 10, 26, 28]. Cotton, on the other hand, has a relatively long cycle and requires a lot of water when grown under full irrigation [13]. The average irrigation requirement for surface-irrigated cotton is reported to be 6000–7000 m3 ha^{-1}, depending on soil, weather conditions, and seasonal rainfall [14, 15].

Some parts of the world, such as cotton-producing areas in the United States of America, have low or no irrigation requirements due to an adequate distribution of rainfall during the growing season. However, several producers use Supplemental Irrigation (SI) to reduce drought stress, reduce risk, and improve yield stability across a wide range of environmental conditions [16]. The need for SI is obviously greater

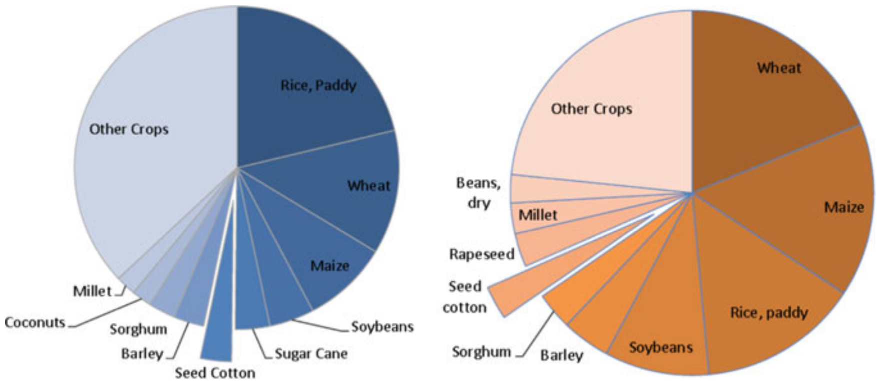

Fig. 4 Global share of agricultural water (left) and land (right) by crop (based on data from Hoekstra and Chapagain (2007) for water and FAOSTAT (2013) for land)

in semi-arid regions due to recurring droughts and long periods of dry spells, which tend to worsen as a result of global climate change [17].

Cotton crops are grown in six major agro-ecological zones in Ethiopia. The major irrigated cotton-producing agro-ecological zones are the hot to warm arid lowlands and the hot to warm semi-arid lowlands, which cover approximately 50% of the total cotton cultivation area. The remaining 50% of cotton coverage is covered by the major rainfed cotton producing agro-ecologies of hot to warm humid lowlands, hot to warm moist lowlands, hot to warm semi-humid lowlands, and Tepid to cool arid mid highlands. However, some rainfed areas, such as tepid to cool arid mid-highland, are marginal cotton production zones because the temperature in these zones occasionally falls below optimum, whereas hot to warm semi-humid lowlands zones are moderate production zones (Cotton research strategy 2016–2030, Ethiopian institute of agricultural research [14]. Implementing a supplement irrigation system in these zones may be beneficial in terms of reducing drought stress, lowering risk, and improving yield stability.

In Ethiopia, an irrigated large cotton farm is currently located in the Afar region. The farm was established in 2008. It now grows 250–350 ha of cotton and employs approximately 90 permanent employees, including a farm manager. Until the crop is in its early stages, mechanization is fully developed, but weeding and picking require 400–600 temporary workers. After plowing, ridging, and pre-planting irrigation, the cotton crop is machine planted in rows at 90 20 cm spacing in May–June. At 3 p.p. hole, the crop is tinned. Irrigation is done every 2 or 3 weeks, depending on the growth stage and water requirement, which is higher during the flowering period. Pest control necessitates 8–12 sprays. In 2019, the average yield of seed cotton per hectare was 3.3 tons.

The irrigation of cotton plants in this mechanized cotton farming region must be optimized through farm management schemes. The installation of modern, efficient irrigation systems should be discussed in light of recurring droughts, as well as a potential opportunity to increase cotton yields.

3.3 Irrigation Management Trends for Sustainable Cotton Production

Geospatial technology advancements have now provided global estimates of the level of water stress in the world. When viewing cotton through the lens of water scarcity indices, it is critical to consider the importance of irrigation to cotton in the region in question, as well as the sustainability of the irrigation water source if irrigation is required.

Irrigation can increase productivity even in humid areas when rainfall is delayed during the season or due to infrequent drought conditions [18]. Irrigation water management is an important tool for increasing land productivity and ensuring that no other inputs are wasted. New technologies have given producers several new tools to use in developing sustainable crop water management strategies. Companies that have taken advantage of widely distributed cellular networks to affordably transmit data from sensor networks monitoring water status in the field near-real time are one example (for example, [19] report recent work at the University of Zimbabwe). This provides farmers with easy access to the water status of the plants in their fields, allowing water to be applied only when necessary.

New technologies are also improving the precision of irrigation water delivery. Subsurface drip irrigation is one example that has been particularly successful for cotton in the southwestern United States, where it is used on over 100,000 ha of cotton [20]. Water is delivered through tubes buried 20–40 cm below the soil surface and beneath the planted row in this system. Water can be applied in small amounts as needed to the crop, and virtually no water is lost due to evaporation.

Another example is the use of global positioning system (GPS) technologies to map changes in the soil within a field and then control sections of an irrigation pivot to apply the volume of water required for the crop growing in that soil type [7]. The combination of sensors and irrigation controllers has resulted in systems that allow for completely automated control of irrigation water. Farmers can now purchase integrated control and wireless data handling systems from all of the major center pivot manufacturers.

3.4 Drip Irrigation and Conservation Tillage

Drip irrigation is a nearly 100% efficient water delivery system. The drip system's main feature is the direct application of water to plant roots via pipes on or below the soil surface (Figs. 5 and 6). This reduces evaporation and increases water use [21]. Conservation tillage is a crop production system that reduces field cultivation. This system frequently employs cover crops, which are planted prior to cotton, to reduce soil erosion and to conserve and trap rainfall within the field. Some cotton pests such as the cotton aphid, Aphis gossypii Glover (Homoptera: Aphidae), are more abundant in non-water stressed plants than in cotton plants grown in dryland [8], whereas the pests such as banded winged whitefly, Trialeurodes abutiloneus Haldeman (Homoptera: Aleyrodidae), are more abundant in water-stressed cotton [19].

The drip irrigation system was first developed in Israel in the 1960s, but it wasn't until the late 1970s that an Israeli company developed the integrated dripping pipe system that is still in use today in field crops (Fig. 7).

This dripping pipe is a continuous pipe with drippers molded every 60–100 cm that comes on 5 km rolls. Farmers install the pipes in the field at the start of the irrigation season and remove them before harvesting. Farmers can use the same pipe for about 20 seasons, so the system's annual cost is reasonable. Water savings range from 20 to 30% when compared to other methods.

Fig. 5 An irrigated California cotton field with hose pipes. *Source* photo of cotton drip irrigation system-Google Suche

Fig. 6 Drip irrigation successful on Pima cotton in El Paso Valley. *Source* photo of cotton drip irrigation system-Google Suche

Fig. 7 Drip irrigated cotton field. Source: M. Yogev, Irrigation management under cotton shortage. The Israel cotton production & marketing board Ltd. Netivot 3, Herzlia, Israel. *Source* 33rd International Cotton Conference: March 16–18, Bremen, Germany (2016)

Farmers are recently using a different method to save more water by burying the pipe at a depth of 40 cm, providing water directly to the root zone while leaving the soil surface dry and avoiding evaporative water loss.

4 Effect of Mechanization on the Cotton Industry

Cotton mechanization practices, cotton ginners, and the cotton industry are all interconnected. Ethiopia has developed agricultural mechanization based on cotton production and the textile industry. Ethiopia is the second largest consumer of cotton in Africa, after Egypt, and a net importer to meet the needs of the country's textile mills. Domestic spinning industries will drive the growth of cotton production. Ethiopia has a lot of potential to grow its spinning industry and become one of the biggest industrial users of cotton. Cotton production has a high potential in the country, and labor and electricity costs are low. Mechanization applications have already begun in some areas. It is necessary to introduce and/or increase the number of particularly powerful and new tractors, pneumatic planters, mounted and self-propelled sprayers for defoliant applications, self-propelled cotton pickers, and so on.

However, there may be some difficulties in mechanized cotton production. Production costs may rise sharply while cotton prices fall concurrently. This contradictory situation may have an impact on farmers and industrialists who invest in technological machines in the cotton industry, such as seeders and self-propelled cotton pickers. To address these issues, many development institutions, practitioners, and experts believe that investments in mechanization technologies such as tractors and cotton harvesting machines, such as tractors and cotton harvesting machines, are required to help Ethiopia emerge from agricultural stagnation [22].

The potential effects of mechanized cotton production provide an interesting field of speculation. It has also been established that cotton mechanization, particularly cotton harvesting, has a direct impact on the quality of cotton fiber, posing a challenge to the textile industries. Machine harvesting effects on neps have been studied, including the effects of harvest timing [23–25] and harvester setup [26], as well as comparisons between spindle and stripped harvested cotton [15, 22, 27] also demonstrated that the level of neps in spindle machine-harvested cotton was related to fiber maturity and linear density caused by differences in boll maturity at harvest. Reference [27] varied the timing of harvest aids to produce differences in boll maturity. The relationships between neps and fiber maturity, fiber linear density (fineness), or micronaire are well established [17, 27, 28] and show that fewer neps are associated with fiber that is more mature as measured by a higher maturity ratio, fiber linear density (fineness), or micronaire. After the ginning process, nep levels were measured in all of these relationships. Increased mechanical handling of lint during the ginning process also leads to an increase in neps, according to studies [23, 27, 29, 28], and differences in neps can be attributed to fiber maturity at harvest.

Lint contamination may also occur as a result of poor cotton production practices. Lint contamination has recently become a major problem for the global cotton industry, affecting both the textile and raw cotton industries. Cotton contamination has an immeasurable total cost. Textile mills around the world have spent an estimated $200 million on equipment that will detect some of the major contaminants in recent years. This is money only to help minimize the problem; it does not include revenue lost due to broken contracts, loss of business, or supplier loss of confidence, despite the fact that effective contamination devices are in place. Even though contamination detection devices are only partially effective, these investments were made.

Lint contamination can appear in a variety of ways in cotton. There are many suspects. Plastic twine, module cover materials (Fig. 8), plastic shopping bags, sewing twine, trash in irrigation ditch liners, sugar, and honeydew (Fig. 9), and colored clothing are all potential contaminants.

The fabric inspection line (Fig. 10, left) is the first place where contaminants are visible in the textile process after the yarns have been woven or knitted, scoured, bleached, and dyed. This is an expensive place to look for contaminants because one contaminated bale tainted several hundred thousand pounds of cotton. Contamination in the finished garment is even more expensive. In this case (Fig. 10, right), we're looking at men's shirts priced between $25 and $60. The garments are practically useless due to contaminants.

Fig. 8 Module cover materials (left) and trashes in cultivation field (right) as a source of lint contaminants. *Source* Andrew G. Jordan: Lint contamination a serious threat to U.S. cotton. 2004 Beltwide Cotton Conference, San Antonio, TX January 5–9

Fig. 9 Aphids and Whiteflies (left) as a source of cotton stickiness and baling twine (right) as a source of lint contaminants. *Source* Andrew G. Jordan: Lint contamination a serious threat to U.S. cotton. 2004 Beltwide Cotton Conference, San Antonio, TX January 5–9

Fig. 10 Fabric inspection (left); Rejected dress shirts (right). *Source* Andrew G. Jordan: Lint contamination a serious threat to U.S. cotton. 2004 Beltwide Cotton Conference, San Antonio, TX January 5–9

5 Best Mechanization Practices for Cotton Industry

Every cotton farmer wants to increase his or her profit. To accomplish this, methods of producing cotton at the lowest possible cost must be developed. Of course, there are issues other than high production costs. Cotton production area reductions, for example, and lowered lint prices are significant. Individual farmers, however, have little control over such matters. Government programs determine cotton cultivation areas and, to a large extent, price subsidies. This leaves one critical factor—production costs, which are under the control of individual farmers. Currently, high labor requirements are the primary cause of high production costs. With current production and hand harvesting practices, 4046.86 m2 of cotton yielding 1 bale (226.8 kg) requires about 100 manhours. During the first and second pickings, a team of 32–35 laborers in Pakistan spent approximately 5–6 h picking one hectare of cotton. With labor becoming scarce and more expensive, reducing labor requirements provides the best opportunity to reduce production costs. It is well documented that the use of machinery can significantly reduce labor requirements for cotton production and harvesting. However, a reduction in labor does not always imply a reduction in production costs unless the machinery is used efficiently and the yields are high enough to justify the investment. Machinery is expensive, and its use must justify the investment. Many individually operated small farms cannot be completely and economically mechanized with the machines now available. This is especially true with regard to mechanical cotton harvesters. The majority of production equipment can be used to produce other crops that are typically included in a diversified farming program, but the cotton harvester can only be used for cotton. A farmer who wants to buy a picker must have enough cotton-producing land (at least 20 ha for smaller pickers) or arrange for custom work. In some cases, a farming program that allows multiple uses of machines can justify the purchase of equipment. A farmer with 5 ha of cotton, for example, might find it cost-effective to purchase a sprayer for applying chemicals for weed control in cotton if the sprayer was also used for applying cotton insecticides, spraying livestock and orchards, or custom spraying.

The latest recommended agronomic and insect control practices for producing high yields must be considered during cotton farm mechanization. High mechanical harvesting efficiency and economical machinery use are aided by good yields of sound bolls. Cotton production and harvesting with mechanical equipment require careful planning. From land selection to harvesting, every stage of mechanized cotton production has a direct impact on the success of the next operation. As a result, it is critical to get off to a good start by carefully selecting land and preparing the seedbed.

5.1 Selection of Land for Mechanization

In addition to selecting good soil capable of producing high yields, it is critical to select land that is suitable for efficient machine operation. Cotton ranks first in terms

Fig. 11 Seedbed preparation. *Source* Integrated crop management. National Cotton Council of America

of available land because the adjustment and operation of planting, cultivating, and harvesting equipment are more critical for cotton than for most other crops. Large fields with long rows are preferable. Fields can often be made larger by removing hedgerows and ditches, as well as changing fencing and road systems. Rocks and stumps that cause machinery breakdowns and obstruct planting, cultivating, and harvesting must be removed. Savings from fewer machine repairs and increased machinery efficiency will soon pay for the removal of rocks and stumps (Mechanized cotton production in Alabama).

5.2 Seedbed Preparation for Mechanization

The primary goals of seedbed preparation are to turn under plant residue, pulverize and farm the soil, and smooth the soil surface (Fig. 11). Seedbed preparation studies revealed that areas with the most thoroughly turned soil surface had the fewest weeds at harvest. To avoid pests, planting in a pest-free seedbed environment with a terminated cover crop containing no green matter is recommended. Shredding stalks, turning under residue, disking to firm soil and remove clods, and smoothing are all part of good seedbed preparation.

5.3 Best-Performing Cotton Variety Selection for Mechanization

The same varieties are recommended for machine harvesting as for hand harvesting. One of the most important characteristics to consider when selecting one of the recommended varieties for machine harvesting appears to be storm resistance. Cotton destined for machine harvesting is frequently left in the field until the majority or all of the bolls have fully opened. As a result, it is exposed to wind and rain for a longer period of time than handpicked cotton. Storm-resistant varieties have less weather or pre-harvest loss while maintaining high machine efficiency (Mechanized Cotton Production in Alabama, 1959). The main two commercial varieties in Ethiopia are still two US varieties bred for irrigated cotton farms, Deltabine 90, released in 1989, and Acala SJ2, released in 1986. Claudia, a more recent variety thought to be of Australian origin, is being bred. Before farms can be mechanized, these varieties must be tested for spindle picker (stripper) harvester tests. This will aid in calculating their yield per hectare. Before mechanization of cotton farms, their storm resistance properties (against wind and heavy rain) must be evaluated, as well as their overall machine efficiency.

6 Comparison Between Manual and Mechanical Cotton Harvesting

To use cotton pickers for harvesting, many changes in cotton cultivation agronomy must be made. The seed rate used for mechanical cotton harvesting is three times that of manual cotton picking. Because the height of the plants must be uniform and much lower than in the conventional method, the plant population must be much higher in order to achieve sufficient yields. Cotton plants grown traditionally will have many more branches and bolls per plant than cotton fields grown for mechanical harvesting.

Mechanical harvesting requires much less inter-row and inter-plant spacing to accommodate a greater number of plants. Cotton plants that will be mechanically harvested must also be sprayed with defoliant chemicals in order for the harvesting process to be clean and efficient. Cotton pickers gather more debris than manual picking, so it must be pre-cleaned before being sent to the cotton gin. All of the above changes in cultivation practices will increase costs, but the yields under this process are expected to be up to 35% higher than the conventional method of cotton cultivation.

7 Cost of Production of Raw and Lint Cotton

For the past 50 years, the Secretariat of the International Cotton Advisory Committee (ICAC) has conducted a cotton survey of the world's cotton producers. Every 3 years, reports on production costs are published. The most recent report, published in October 2016, is based on data from the fiscal year 2015/16. Ethiopia was 1 of 31 countries that participated in the survey, accounting for 87% of the world cotton area (ICAC 2016).

According to this survey, the net cost of cotton lint production decreased in 2015/2016 after years of continuous increases. In 2015/16, the net cost of producing a kilogram of lint, which excludes land rent and the value of seed after ginning, decreased by 23% to $1.16. The 34 cts/kg of lint produced decrease is due to two major factors: (1) There have been no increases in input costs. Insect control, weed control, ginning, and harvesting costs have all decreased. The cost of fertilizer per kilogram of lint produced remained unchanged from 2012/13; and (2) the value of commercial seed after ginning increased by approximately 50% in 2015/16 compared to 2012/13.

The average cost of producing seed cotton (before ginning) was $0.43/kg in 2009/10 and $0.52/kg in 2012/13, and it had been increasing since at least 2000/01. The cost of producing a kilogram of seed cotton doubled in 15 years, from $0.25 in 2000/01 to $0.52 in 2012/13. For the first time, this trend has reverted, with a net cost of production of seed cotton of $0.46/kg in 2015/16. The ICAC seed cotton cost calculations assumed that farmers are self-cultivators and do not pay rent for land use, as do small-scale cotton farmers in Ethiopia. The lower cost of production of seed cotton (before ginning) corresponds to the lower net cost of production in lint/kg (after ginning). The net cost of producing lint fell from $1.50/kg in 2012/13 to $1.16/kg in 2015/16.

The average net cost of production per hectare in 2015/16 was $1,006 under irrigated conditions and $776 under rainfed conditions, both lower than in 2012/13. Lint yielded 957 kg/ha under irrigated conditions and 647 kg/ha under rainfed conditions in 2015/16. Cotton is less expensive to produce under irrigated conditions due to higher yields than under rainfed conditions. The cost of a kilogram of lint produced under irrigated and rainfed conditions is $1.05 and $1.20, respectively. In 2015/16, irrigated conditions provided 69% of global production. In 2015/16, irrigation cost only 7 US cents per kilogram of lint produced. This data demonstrates that effective irrigation farming allows for the production of lint cotton at a lower cost than rainfed farming. The following chart (Fig. 12) depicts the cost structure of lint cotton (after ginning) production on a global scale.

In terms of the total cost of lint production, 18% (36 cents) of the total cost was spent on renting land to produce a kilogram of lint (ginned cotton). Fertilizers were

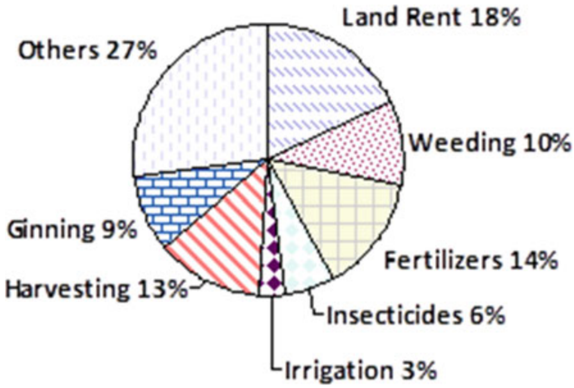

Fig. 12 Structure of cost of lint cotton production—world average. *Source* A report by the technical information section of the International Cotton Advisory Committee, October 2016 Washington DC USA

the most expensive input, accounting for 14% of the gross cost (27 cents/kg lint produced), followed by 13% (24 cts/kg) for harvesting/picking and 10% (21 cts/kg) for weeding. In 2015/16, the cost of insect control was only 6% of the total production cost, a decrease of over a decade. Irrigation costs only 3% of the total. The reported cost of irrigation, like all other inputs and operations, represents the average cost of irrigation per kilogram of lint produced in all participating countries during the study. In some cases, the 10 cts/kg lint spent by producers on planting seeds includes the technology fee for biotech trait(s). In addition to the operations and inputs not listed in the pie chart, the 'others' category includes economic costs, fixed costs, and fixed costs. The national average cost of producing one hectare of cotton in Ethiopia is shown in Table 2.

Table 2 shows that the harvesting cost for one hectare of cotton is $171.50 (3,720.00 Birr). According to the report, Ethiopia relies entirely on manual harvesting. In the same report (separate tables), the cost of harvesting one hectare of cotton spent by some world countries that use 100% manual harvesting is presented: Sudan $155.00/ha, Uganda $37.80/ha, Nigeria 86.67/ha, Mali $103.21/ha, Indonesia $92.59/ha, Pakistan $161.59/ha, Paraguay $144.23/ha.

Why the cost of manual harvesting in Ethiopia is higher than in the other countries mentioned needs to be investigated further. However, in Ethiopia's future plan to cultivate more land while keeping labor costs under control, mechanized harvesting will play a critical role.

8 Summary

Cotton occupies a unique position in Ethiopia's agrarian economy. Ethiopia has enormous potential for the production of cotton. Ethiopia has favorable weather and topography for cotton cultivation and production. Cotton (Gossypium hirsutum L.) is currently widely grown in irrigated lowlands on large-scale farms and in warmer mid-altitudes on small-scale farms under rainfed conditions. According to a recent Ministry of Agriculture study, there is 3,000,810 Ha of land suitable for cotton production, whereas it is currently limited to a maximum of 100,000 ha. Cotton demand is expected to remain strong in Ethiopia, and there is a clear need to improve productivity in future to meet this rising demand. Ethiopian cotton production is hampered by low productivity, which is caused by rainfed cultivation, small farm size, increasing pest and disease, and labor-intensive cultivation methods. Because labor costs in Ethiopia are rapidly rising, mechanization in cotton cultivation will be critical in keeping costs under control. Furthermore, high-density planting will result in increased productivity. However, high-density planting combined with mechanization necessitates the development of sympodial cotton hybrids as well as a complete transformation in agronomy practices.

Table 2 Cost of producing one hectare in Ethiopia (National Average)

Operation/Item	Unit	Quantity per ha	Cost or price per unit	Cost in Birr	Cost in US $
1. Pre-sowing					
Land rent for cotton	ha	1.00	150.00	150.00	6.92
Land revenue/tax	ha	1.00	60.00	60.00	2.77
Pre-soaking irrigation				210.00	9.68
Plowing	number	2.00	1500.00	3000.00	138.31
Planking					
Other					
Sub-total				**3420.00**	**157.68**
2. Sowing					
Soaking irrigation					
Land preparation				660.00	30.43
Seed				400.00	18.44
Seed treatment				95.00	4.38
Herbicides (Pre-sowing)					
Fertilizer					
Drilling					
Other				75.00	3.46
Sub-total				**1,230.00**	**56.71**
3. Growing					
Thinning				70.00	3.23
Weeding		3.00	162.00	630.00	29.05
Hoeing		3.00	162.00	630.00	29.05
Herbicides (Post-sowing)					
Fertilizer (Total)					
Irrigation		5.00	124.00	950.00	43.80
Insecticides		5.00	250.00	1,400	64.55
Defoliation					
Other					
Sub-total				**3680.00**	**169.68**
4. Harvesting					
Picking cost					
a. Hand picking (100%)		1.76	2,000.00	3,520.00	162.29

(continued)

Table 2 (continued)

Operation/Item	Unit	Quantity per ha	Cost or price per unit	Cost in Birr	Cost in US $
b. Machine picking (%)					
Stick cutting/ slashing				200.00	9.22
Other					
Sub-total				**3,720.00**	**171.51**
Seed cotton costs				**12,050.00**	**555.56**
5. Ginning					
Transportation to gin factory	ton	1.76	1,200.00	2,112.00	97.37
Ginning (Including bagging)	ton	1.76	1,300.00	2,288.00	105.49
Classing/grading charges					
Other					
Sub-total				**4,400.00**	**202.86**
Variable cash costs				**16,450.00**	**758.41**
6. Economic costs					
Management and administrative					
Interest on capital invested					
All repairs					
General farm overheads					
Other				148.05	6.83
Sub-total				**148.05**	**6.83**
7. Fixed costs					
Power supply					
Irrigation system at the farm					
Tractors					
Spray machinery					
Farm implements					
Other				213.85	9.86
Sub-total				**213.85**	**9.86**

(continued)

Table 2 (continued)

Operation/Item	Unit	Quantity per ha	Cost or price per unit	Cost in Birr	Cost in US $
8. Total cost				16,811.90	775.10
9. Value of seed cotton	**kg**	1,760.00	12.00	21,120.00	973.72
10. Net Value of lint	**kg**	650.00	33.00	21,450.00	988.93
11. Net Value of seed	**kg**	1,110.00	6.80	7,548.00	347.99

Source A report by the technical information section of the International Cotton Advisory Committee, October 2016 Washington DC USA

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