Environment, Development and Sustainability
https://doi.org/10.1007/s10668-023-03961-z

The irrigated wheat initiative of Ethiopia: a new paradigm emulating Asia's green revolution in Africa

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Received: 21 February 2023 / Accepted: 20 September 2023

Abstract
The aim of this paper is to assess and document the experience of the successful irrigated wheat initiative in Ethiopia, identify potential limitations, and suggest alternative options that contribute towards the sustainability of the program. In the past decades, Ethiopia has initiated several projects to ensure food and wheat security but did not achieve the anticipated impact as planned. In 2019, however, the current government of Ethiopia put in place structural, economic, and sectorial reforms, with wheat chosen as a strategic commodity for food security, raw material for the agroindustry, import substitution that transits to export, and job creation along the value chain. With a total of 2.6 million ha of land cultivated under both rain-fed and irrigated systems, followed by a record amount of wheat harvest (8.2 million tons) in 2022, Ethiopia achieved a wheat self-sufficiency ratio of 100% and more than 1 million tons of surplus for export, indicating that the new irrigated wheat initiative of Ethiopia has been found transformational and is becoming a game changer. Moreover, modest case scenario projections revealed that Ethiopia will become a net exporter of wheat by 2023, indicating that the country is achieving not only wheat security but also championing the possibility of replicating Asia's Green Revolution in Africa. Yet, the sustainability of the current initiative relies on an efficient water management system, private sector engagement, sustainable input supply, well-established input and output marketing systems, and leadership commitment at all levels.

Keywords Homegrown economic reform · Ethiopia · Food security · Asian green revolution · Irrigated wheat initiative

1 Introduction

It has been abundantly archived in scientific literature that, driven by the technology revolution, comprising a package of modern inputs, irrigation, improved seed, fertilizers, and pesticides, the Green Revolution in Asia was one aspect of a much larger transformation of global agriculture during the twentieth century, through which most countries pulled back from the edge of famine. On the other hand, since Africa is missing out on the scientific

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breakthroughs that revolutionized agriculture in other developing countries (Ejeta, 2010), the continent continues to be the exception to the Asian and global trend (Pingali, 2012) and is still wallowing in the specter of widespread food shortages and poverty. Thus, instead of showing progressive improvements to meet the Sustainable Development Goals, the 2023 Global Report on Food Crises revealed that Africa's global food insecurity has hit an all-time high, driven by a combination of conflicts, climate change, and rising prices of food, fuel, and fertilizers. The situation has been further exacerbated by the impacts of the COVID-19 pandemic and conflicts in Ukraine (Global Food Crises Report, 2023). The report indicates that Sub-Saharan Africa is the most affected region in the world. This is a clear indication of the fact that humanity has failed to make progress towards Sustainable Development Goal 2, to end hunger and achieve food security and improved nutrition for all.

Ethiopia is one of the signatories to the universal development agenda known as the Sustainable Development Goals (SDGs), which comprises 17 goals with 169 associated targets. Among the 17 SDGs, the first two top global goals are the most important ones that developing nations, particularly Sub-Saharan Africa (SSA), are struggling to cope with. In Ethiopia, the first two SDG Goals (ending poverty in all its forms everywhere and zero hunger, respectively) are the major bottlenecks that have put humanity at risk, leading to unending dependency on foreign food aid for survival.

Reports show that Ethiopian people living below the poverty line are estimated at 24% (World Bank, 2020). 12.8–15 million people suffer from chronic hunger and are in critical need of food aid every year (National Disaster Risk Management Commission and UNOCHA, 2020), with the prevalence of stunting among children under five as high as 37% (Ethiopian Public Health Institute & World Food Program, 2022). Furthermore, the 2021 report on the Global Hunger Index (GHI, 2022) shows that the state of chronic food insecurity and malnutrition in Ethiopia is categorized as serious, with the country standing 90th out of the 116 countries with a GHI score of 24.1. Assessments of overall nutritional status indicators (level of malnutrition, stunting, and wasting) of all age groups are categorized as "very high" in Ethiopia (UNICEF, 2019).

Interestingly, however, Ethiopia's perennial problem of food insecurity is paradoxical. On one hand, the country has ample arable land, which is estimated at 16.20 million ha (FAO, 2016). Evidence also shows that irrigable land is estimated at 3.8 million ha with an economic irrigation potential of about 2.7 million ha (Awulachew, 2010; FAO, 2016). Likewise, the country is endowed with 12 major river basins with an annual runoff volume of 122 billion m^3 and underground water potential that is estimated at 2.6–6.5 billion m^3 (Awulachew, 2010). Huge amounts of rain also fall in the country, most of which is not harvested for irrigation. Endowed with this massive renewable water resource, Ethiopia is often described as "the Water Tower of Africa". In contrast, however, much of its potentially and economically irrigable land is unexploited, with only 5% of the potential land cultivated using irrigation (Worqlul et al., 2017). Several of the country's rivers flow and end up in oceans (Wabi Shebelle, Genale, and Dawa), seas (Awash, Afar-Danakil, and Blue Nile), or lakes (Omo and Ghibe), with very little being tapped for irrigation. The situation is further exacerbated by the fact that most of the potentially irrigable land, which can guarantee multiple harvests per year, is either idle for half of the year or poorly cultivated.

These realities accentuate the fact that potential alone does not guarantee national food security or reduce poverty. Exiting potential and opportunities need to be tapped and fully exploited through locally developed and relevant technologies, accompanied by building up human and institutional capacity with supportive national policies and committed leadership to attain food security (Ejeta, 2010). Nor blaming other factors for the failure to attain food and nutrition security has no justification whatsoever. From the viewpoint of existing resource potential, it seems that inappropriate agricultural policies and a lack of leadership commitment could be the major factors that have kept the country dependent on foreign food aid.

In addition to the country's inability to unleash its potential through irrigated food production, the current food insecurity situations in Ethiopia and elsewhere in the developing world are further exacerbated by the on-going global food crises, the COVID-19 pandemic, global climate change, and the on-going full-scale conflict between major wheat-producing and exporting nations in the world. To overcome the looming national and global challenges, the Federal Democratic Republic of Ethiopia has recently launched a new national development policy reform known as Homegrown Economic Reform, where a new irrigated wheat production initiative has received a top development priority as a pathway to end the vicious cycle of pervasive poverty and hunger and eventually to become the beacon of African prosperity.

To make this happen, Ethiopia followed a two-pronged approach: (1) bridging the yield gap in traditional highland wheat growing areas through developing and scaling climate-resilient high-yielding varieties and associated crop management practices; and (2) expanding wheat production in new frontiers of irrigated systems in both lowland and highland areas (Tadesse et al., 2022).

Moreover, what makes the irrigated wheat initiatives of Ethiopia overwhelmingly popular is the fact that the initiative was launched not only at a critical time when the performance assessment of the Alliance for a Green Revolution in Africa (AGRA), one of the biggest agricultural development organizations established by a consortium of major global donors, has reportedly failed to meet its self-declared deadline but also at a time when Africa is agonizingly facing serious shortages of global wheat supply. To cut a long story short, AGRA was aiming at replicating in Africa the type of first Green Revolution that swept through much of Asia and Latin America in the 1960s and 1970s. This was intended to be done through subsidizing the purchase of commercial seeds and fertilizers, with the objective of doubling crop productivity and farmers' incomes while halving food insecurity by 2020 and reaching 30 million smallholder farming households in 13 African countries (Wise, 2020).

However, an impact assessment of AGRA by Wise (2020) revealed that productivity increased just by 29% over a 12-year period for maize, the most subsidized and supported crop. This falls well short of doubling yields, which should have been a 100% increase. The overall yields of staple crops have grown by only 18% over the 12-year period. Meanwhile, undernourishment (as measured by FAO) has increased by 30% in AGRA countries, implying that AGRA made an unfulfilled promise to develop African agriculture (Wise, 2020).

Wise (2020) overtly criticized AGRA's failure was originated from seeking to import Western technologies that are inappropriate for Africa's settings and peculiarities. The organization ignored considering the continent's unique soils, farmers, and food systems, lacked consultations with African farmers on the nature of the interventions, etc. Unlike the first Green Revolution, the assessment report indicated that AGRA's intervention has rather damaged Africa's existing resources. According to the assessment report, water supplies have been depleted and contaminated with chemical run-off; farmers indebtedness has increased due to high input costs while yields have declined; and crop and diet diversity have been lost as only selected "Green Revolution crops" dominated the countryside, indicating that the return to AGRA's heavy investment have been negative.

Therefore, the success story of Ethiopia's Homegrown Economic Reform and the irrigated wheat initiative can be taken as an alternative and a lesson that could be learned from as compared to accepting and implementing donor-driven and donor-funded agricultural development initiatives in Africa. Thus, donor-driven agricultural development initiatives should be anchored on the consensus of donor-recipients and win–win approaches not only to ensure the sustainability of agricultural development but also to avoid negative long-term impacts on the environment.

The aim and scope of this paper are, therefore, to critically assess existing resource potential for irrigated wheat production and suggest prerequisites for the effectiveness and sustainability of the initiatives as well as to demonstrate the possibilities of replicating Asia's Green Revolution in Africa.

2 Problem statement

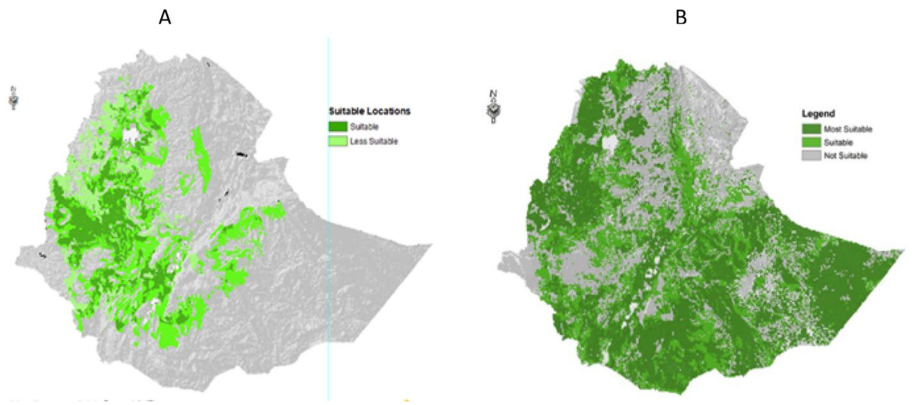
Ethiopia is one of the largest wheat-producing countries in sub-Saharan Africa. Wheat is cultivated on a total area of 1.7 million hectares annually, with a total production estimated at between 5 and 6 million tons. However, there is huge demand–supply variance for wheat due to rapid population growth, changes in food preferences for value-added products, rural–urban population demographic shifts, climate change, increasing food prices due to the COVID-19 pandemic, and national and global conflicts. To counterbalance the widening demand–supply gap, Ethiopia spends more than USD 700 million per year to import wheat grain. Thus, this paper tells the tale of how the new irrigated initiatives launched by the Ethiopian government transformed the overall Ethiopian wheat sector and how the country gradually emerged as a net exporter of wheat within a short period of time.

3 Study methodology and data sources

The dataset used in this study was generated from two sources. The first dataset was generated from a comprehensive desk review of available literature on relevant policies, resource assessment reports, and other relevant sources. The second dataset was generated from the wheat field data recorded by the Ethiopian Institute of Agricultural Research (EIAR), the Oromia Bureau of Agriculture (OBA), and the Ethiopian Agricultural Transformation Institute (ATI). Furthermore, suitability maps of the rainfed and irrigated wheat systems of Ethiopia were reconstructed using all biophysical variables, including altitude, rainfall patterns, underground water, temperature, soil types, soil pH and slope for soil drainage (Fig. 1A, *B), an area delineation technique that has never been used before. Some of the biophysical variables identified for the rainfed wheat system include:

- Altitude ranging from 1500 to 3200 m above sea level
- Rainfall ranging from 500 to 1200 mm
- Growing temperatures ranging from 15 to 25 °C
- Soil: *vertisols, andisols, luvisol, and nitosols*
- pH ranging from slightly acidic (5.5) to slightly alkaline (7.5)
- Drainage: Well-drained soil
- Slope: 3–5%

Some of the biophysical variables identified for the irrigated wheat system include:



Figs. 1 Wheat suitability map reconstructed using biophysical variables for rainfed (**A**) and irrigated systems (**B**) in Ethiopia

- In all climates with altitude ranging from 0 to 3700 m above sea level.
- Growing temperature ranging from 20 to 25 °C.
- Soil: *vertisols, andisol, luvisol and nitosols, cambisols, phaeozems, calcisols, gypsisols, luxisols, ferralsols* soils.
- Drainage: slightly to well-drained soil
- Slope: 0–3%
- pH ranging from slightly acidic (5.5) to slightly alkaline (8.0).

3.1 Wheat varieties used in the irrigated wheat system

Some of the locally developed wheat varieties deployed for use in the present irrigated wheat initiative in Ethiopia are listed in Table 1. The locally developed wheat varieties have been developed predominantly through hybridization between introduced exotic germplasm acquired through the Consultative Group for International Agricultural Research (CGIAR) and locally collected landraces. The wheat breeding program in the National Agricultural Research System focuses on core traits, with some emphasis on additional traits for specific environments. Agricultural Research Centers located in strategic environments are responsible for crossing, selecting, developing, and distributing stable and high-yielding advanced lines with durable pest resistance, stress tolerance, and superior-quality early-generation seeds using different strategies and breeding methods.

3.2 Governance structure and institutional arrangements of the irrigated wheat initiative in Ethiopia

A flowchart on the governance structure and institutional roles of the irrigated wheat initiative in Ethiopia is depicted in Supplementary Table 1 and Fig. 2. The Ethiopian irrigated wheat initiative was first conceptualized by the Ethiopian Institute of Agricultural Research (EIAR) and later owned by the Ministry of Agriculture (MoA) and the Office of the Prime Minister. The MoA assigned the EIAR to serve as a project-coordinating

Table 1 Locally developed wheat varieties targeted for different agro-ecological zones of Ethiopia. *Source*: (EIAR, 2022)

No	Variety groups	Maturity groups	Adaptation zones	Year of release
1	Were-1	Early maturing	Lowland	2008
2	Were-2	Early maturing	Lowland	2013
3	Ga'aambo	Early maturing	Lowland	2011
4	Ga'aambo 2	Early maturing	Lowland	2017
5	Fentale	Early maturing	Lowland	2015
6	Fentale 2	Early maturing	Lowland	2017
7	Amibara	Early maturing	Lowland	2015
8	Amibara 2	Early maturing	Lowland	2017
9	Ardi	Early maturing	Lowland	2019
10	Lucy	Early maturing	Lowland	2013
11	Dursa	Early maturing	Lowland to midland	2020
12	Kekeba	Early maturing	Lowland to midland	2010
13	Ogolcho (ETBW5520)	Early maturing	Lowland to midland	2012
14	Kingbird	Early maturing	Lowland to midland	2015
15	Wane (ETBW6130)	Early maturing	Lowland to midland	2016
16	Deka (ETBW7638)	Early maturing	Lowland to midland	2018
17	Balcha (ETBW8260)	Early maturing	Lowland to midland	2019
18	Gelan	Early maturing	Lowland to midland	2019
19	Dandaá	Late maturing	Highland	2010
20	Hulluqa (ETBW5496)	Late maturing	Highland	2011
21	Shorima (ETBW5483)	Late maturing	Highland	2011
22	Hidasse (ETBW5795)	Late maturing	Highland	2012
23	Lemu (ETBW6861)	Late maturing	Highland	2016
24	Boru (ETBW9554)	Late maturing	Highland	2020

*Lowland agro-ecologies (< 1500 masl; annual rainfall between 500 and 800 mm); midland agro-ecologies (between 2200 and 2400 masl; annual rainfall > 800 and < 1000 mm); highland agro-ecologies (> 2400 masl; annual rainfall > 1000 mm); early maturing (81–100 days); late maturing group > 115 days depending up on local climate

entity, with the role of providing general oversight and technical backstopping for effective implementation.

The MoA also cascades down the initiative to the regional states, which play key roles in implementing the initiative. The Regional Bureau of Agriculture took on the overall responsibility of coordinating the initiative in the regions by organizing and overseeing other institutions such as regional research institutes, cooperatives and unions, zonal agricultural development offices, regional seed enterprises, universities, and other actors, where each actor has specific roles and responsibilities to play in the initiative.

The overall progress has been overseen by a steering committee established at all levels, from the federal level down to the district levels and beyond. The steering committee played key roles in fixing emergent issues unaddressed during the planning phase.

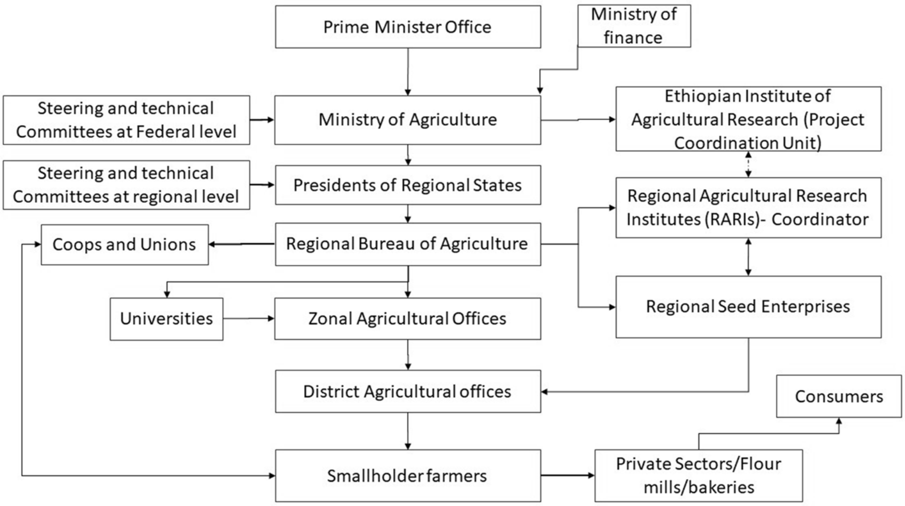


Fig. 2 Flowchart depicting governance structure and institutional roles in the irrigated wheat irrigated wheat initiative of Ethiopia

3.3 Potential limitations

It is indisputable that the sustainability and scalability of any new initiative depend on the accuracy, reliability, and uniformity of the data collected and the availability of a centrally managed database platform. However, the data used in this report was recorded and managed by different institutions and regions that use different database platforms. Thus, the absence of a dedicated and centralized database may cast a shadow on the reliability of the data and the information generated.

3.4 Irrigation potential and hydro-political dynamics in Africa

An extensive study by the Malabo Montpellier Panel Report (2018) on the irrigation potential of Africa indicated that the continent's irrigated agriculture is in its infancy stage. The report shows that a mere 6% of the cultivated land is irrigated in Africa, compared to 14 and 37% in South America and Asia, respectively. Of this 6%, more than two-thirds (7.7 million ha) are concentrated in just five countries: Egypt, Algeria, Morocco, South Africa, and Sudan, each of which has more than a million hectares of irrigated land, while the rest of Africa shares only 2.7 million hectares of irrigated land.

On one hand, the potential to increase irrigation in Africa is high, estimated at 47 million hectares (Malabo Montpellier Panel Report, 2018). Considering both land and water resources, the study showed that much of the increase would take place in Sub-Saharan Africa, where irrigated land could be expanded to 38 million hectares, up from the current 7.7 million.

On the other hand, evidence shows that climate change and population growth lead to the problem of water. Scholars (Farinosi et al., 2018) predicted that there's a 75–90% chance of wars being fought over water, not oil, within the next century. The hotspots identified by the research team include the Ganges–Brahmaputra region, where the water flows through Bangladesh and India; the Colorado River, which runs through the United States and Mexico; the Indus region, which has water bodies separating India and Pakistan; the Tigris-Euphrates River, which flows through Turkey, Syria, Iraq, Iran, and Kuwait; and the Nile, which runs through 10 East African countries from Burundi to as far as Egypt in the north of Africa.

The Tigris-Euphrates River, which is quoted several times in the Biblical verses of Genesis and Revelation and known as one of the four rivers that surround and irrigate the Garden of Eden, is reportedly drying up due to climate change, human pressure, socioeconomic conditions, and topographic characteristics (Farinosi et al., 2018).

As argued by Rena-Ramos et al. (2022), freshwater is a strategic natural resource in any region of the world, and this is especially true for Sub-Saharan African countries. However, Sub-Saharan African states, where water ecosystems are strategic resources, are oriented towards regional conflict rather than cooperation. Nowadays, a commonly recognized confrontation over trans-boundary freshwater resources in Sub-Saharan Africa is the regional tensions between Ethiopia and two downstream countries (Egypt and Sudan) over the construction of the Grand Ethiopian Renaissance Dam (GERD) along the Nile River. For the first time in the history of the organization, the United Nations Security Council (UNSC) convened more than 12 times over the GERD after failed hydrodiplomacy discussions between the three countries.

The increasingly brewing feud over the Nile River between the three Nile countries, namely, Egypt, Sudan, and Ethiopia, has its origins in the water use treaties that were signed between the British Colonial Empire on one side and Egypt and Sudan on the other side, to which Ethiopia was not party because of being sidelined from the treaties. This happened even though more than 86% of the waters of the Nile come from Ethiopia.

To date, equitable use of water resources has received the highest-level priority at a global level, where its appropriate and equitable use is included in the Sustainable Development Goals (SDG 2030). In the SDG, water resource use and appropriation are listed under SDG Goal No. 6 with eight targets, where Targets 6.4 and 6.5 emphasize ensuring sustainable withdrawals and supply of freshwater to address water scarcity and implementing integrated water resources management at all levels, including through trans-boundary cooperation as appropriate, respectively. Therefore, recognizing and respecting the SDG 2030, signed, and ratified by all member states of the United Nations, and the consensual win–win declaration of principles signed in 2015 between Ethiopia, Egypt, and Sudan are the basis for preventing conflicts, military buildup, and conceivable arms races in the region.

4 Results

4.1 Assessment of existing resource potential of Ethiopia

4.1.1 Agricultural land

Land areas allocated for various agricultural activities in Ethiopia are shown in Table 2. Ethiopia has one of the largest land areas in Africa, which is estimated at 112 million hectares (Awulachew et al., 2010). Cultivable land area estimates vary between 30 and 70 million hectares. Estimates of the country’s size of land under cultivation vary in literature. It is estimated at 15,000,000 ha (Awulachew et al., 2010), and a recent official report by

Table 2 Basic statistics of land area allocated for various agricultural activities in Ethiopia. *Source*: FAOSTAT (2020)

Physical areas	Year	Area (proportion)	Unit
Area of the country	2020	113,624,000	ha
Agricultural Land	2020	38,476,100	ha
As % of the total area of the country	2020	33.8	%
Arable land	2020	16,195,100	ha
Land under permanent crops	2020	2,281,000	ha
Land under permanent meadows and pasture	2020	20,000,000	ha
Arable Land	2020	16,195,100	ha
As % of total Agricultural land of the country	2020	42.1	%
Land under temporary crops	2020	12,297,930	ha
Land under temporary meadows and pasture	2020	1,886,134	ha
Land with temporary meadows	2020	2,011,030	ha

the Central Statistical Agency (CSA, 2020) estimates that the total land under cultivation in Ethiopia is 15,082,434 ha. The size of land under irrigated cultivation also varies in the country. For the existing cultivated area, estimates show that only about 4–5% of the land is irrigated in the country, with existing equipped irrigation schemes covering about 640,000 ha (Awulachew et al., 2010). Over a period of 10 years, the size of irrigated land has doubled and is currently estimated at 1,304,493 ha (CSA, 2020), raising the present total irrigated land to 8%.

During the 2019/20 cropping season, the total land area allocated for wheat production was estimated to be 1,789,372 ha (CSA, 2020) out of which only 3773 ha were cultivated through irrigation. However, following the current irrigated wheat initiative, the land allocated for irrigated wheat production has reached 669,003 ha.

Assessments of the River Basin Master Plan conducted by the Food and Agricultural Organization (FAO, 2016) and other studies indicated that there was a maximum irrigation potential of about 5.7 million ha in Ethiopia, but only about 3.7 million ha is commonly quoted. Considering the availability of water and land resources, technology, and finance (FAO, 2016), the economic irrigation potential of Ethiopia at present is estimated at about 2.67 million ha. This shows the fact that Ethiopia has exclusively high irrigation potential in all agro-production systems, particularly in the lowlands.

4.1.2 Water resources

Ethiopia is endowed with a substantial amount of renewable water resources (Table 3) but very high hydrological variability (FAO, 2016). Evidence from the same source and Awulachew et al. (2010) show that Ethiopia has 12 river basins with an annual runoff volume of 122 billion m^3 of water and an estimated 2.6–6.5 billion m^3 of groundwater potential. This makes an average of 1575 m^3 of physically available water per person per year, a relatively large volume (Awulachew et al., 2010). Huge amounts of rain also fall in the country every year, of which only a paltry amount is harvested for irrigation. As a result, Ethiopia is often described as “the Water Tower of AfricaHowever, this notable water resource potential is untapped due to an underdeveloped water storage structure. Moreover, there is also a large spatial and temporal variation in rainfall amounts in the country. As a result, there is not

Table 3 Major river basins and potential irrigable land of Ethiopia. *Sources*: Extracted and compiled from Awulachew et al. (2010) and FAO (2016)

Major drainage system	River basin	Area (ha)	As % of total area	Annual runoff (million m^3/yr)	As % of total runoff	Potential irrigable land (ha)	Economic irrigation potential (ha)
Nile basin		36 881 200	32.4	84 550	69	1,918,472	1,312,500
	Blue Nile	19 981 200	17.6	52 600	42.9	815,581	523,000
	Baro-Akobo	7 410 000	6.5	23 600	19.3	1019 523	600,000
	Setit-Tekeze/Atbara	8 900 000	7.8	7 630	6.2	83,368	189,000
	Mereb	570 000	0.5	260	0.6	-	500
Rift Valley		31 764 000	27.9	29 020	23.7	500,125	731,700
	Awash	11 270 000	9.9	4 600	3.7	134,121	205,400
	Afar-Danakil	7 400 000	6.5	860	0.7	158,776	3000
	Omo-Gibe	7 820 000	6.9	17 960	14.7	67,928	384,000
	Central Lake	5 274 000	4.6	5 600	4.6	139,300	139,300
Shebelle-Juba		37 126 400	32.7	8 950	7.3	1,312,625	627,300
	Wabi Shebelle	20 021 400	17.6	3 150	2.6	237,905	204,000
	Genale-Dawa	17 105 000	15.1	5 800	4.7	1,074,720	423,300
North-East Cost		7 930 000	7	0	0		0
	Ogaden	7 710 000	6.8	0	0	–	0
	Gulf of Aden/Aysha	220 000	0.2	0(Awulachew et al. 2010)	0	–	0
Total		113 681 600	100	122 000	100	3,798,782	2,671,500

enough water for most farmers to produce more than one crop per year, and the incidence of crop failure is a common phenomenon, particularly in dry spells and lowland areas of the country (Awulachew, 2010). Besides, most of the rivers in Ethiopia are seasonal, and there are almost no perennial rivers in areas that have an altitude lower than 1500 m above sea level (FAO, 2016). About 70% of the total runoff takes place during the period between June and September, leaving only 30% of the runoff to take place during the dry season. Dry-season flow originates from springs, which provide base flows for small-scale irrigation (FAO, 2016).

According to FAO (2016) the 12 major river basins of Ethiopia form the following four major drainage systems.

- The Nile basin (including Abay or Blue Nile, Baro-Akobo, Setit-Tekeze/Atbara, and Mereb) covers 33% of the country's water resources. It drains the northern and central parts westwards to Sudan, Egypt, and the Mediterranean Sea
- The Rift Valley (including Awash, Denakil, Omo-Gibe Rivers, and Central Lakes) covers 28% of the country's water resources. It consists of a group of independent interior basins extending from Djibouti in the north to the United Republic of Tanzania in the south, with nearly half of its total area being located in Ethiopia
- The Shebelli-Juba basin (including Wabi-Shebelle and Genale-Dawa) covers 33% of the country's water resources. It drains the southeastern mountains towards Somalia and the Indian Ocean.
- The North–East Coast (including the Ogaden and Gulf of Aden Basins) covers 6% of the country's water resources.

Excluding the Great Ethiopian Renaissance Dam (GERD), one of the newly built and largest artificial lakes ever created, Ethiopia has 11 fresh and 9 saline lakes, 4 crater lakes, and over 12 major swamps or wetlands as part of its surface water resources.

Moreover, Berhanu et al. (2014) have identified that there are irrigation potential sites in the major river basins. The total potential irrigable land in Ethiopia is estimated to be around 3.7 million hectares, and this value is consistent with the report of FAO (2016) (Table 3).

4.1.3 Favorable climate

Ethiopia is characterized by a wide variety of landscapes, with marked contrasts in relief and altitudinal ranges from about 155 m below sea level at Assale Lake in the Danakil depression to about 4533 m above sea level at Ras Dejen (Ethiopian Meteorological Agency, EMA, 1988).

The climate of Ethiopia is, therefore, mainly controlled by the seasonal migration of the Inter-tropical Convergence Zone (ITCZ) and associated atmospheric circulations, as well as by the varied and complex topography of the country. Landscapes with contrasting characteristics in terms of physiography and elevation, such as the highlands and the lowlands, experience a variety of climatic conditions varying from desert climate to that typical of equatorial mountains (Fazzini et al., 2015).

In a country such as Ethiopia, whose economy is heavily dependent on rain-fed agriculture, understanding the climatic conditions is useful in understanding the geomorphology of the land, including landforms and the morpho-dynamic evolution of natural landscapes.

In the same way, the recently launched irrigated wheat initiatives in Ethiopia also require a deep understanding of the climatic conditions of the country that govern rainfall pattern and distribution. Furthermore, it is also important to understand disease and pest dynamics, such as locust invasions, and make accurate predictions on the frequency of the devastating drought as it emerges following changes in climatic variables.

4.2 Drivers for irrigated wheat initiatives in Ethiopia

In Ethiopia, key drivers of irrigated wheat initiatives can be broadly categorized into internal and external factors. Internal factors include rapid population growth, increasing urbanization, a large trade deficit in agricultural products, and sustained internal conflicts that left millions of people chronically food insecure. External factors include declining foreign budgetary aid and associated supports associated with the internal conflicts that the country has been bearing, the global COVID-19 pandemic, and rising global food and fuel prices, mainly because of the conflicts between Russia and Ukraine. These and other factors have increasingly worsened the already widening demand–supply gap for staple food crops such as wheat (Fig. 3).

4.3 Demand–supply Gap

A combination of official and administrative data retrieved from FAOSTAT (2022) from 2001 and 2020 (Fig. 3) proves that Ethiopia is one of the net wheat-importing countries in Sub-Saharan Africa. Ethiopia's national wheat deficit ranges between 1.2 and 1.7 million tons per annum, with an estimated average import value ranging from US$98,500,000 in 2002 to US$ 733,276,000 in 2016. The reprehensible part of Ethiopian wheat imports is that the limited hard currency earned by the country from exports of other agricultural

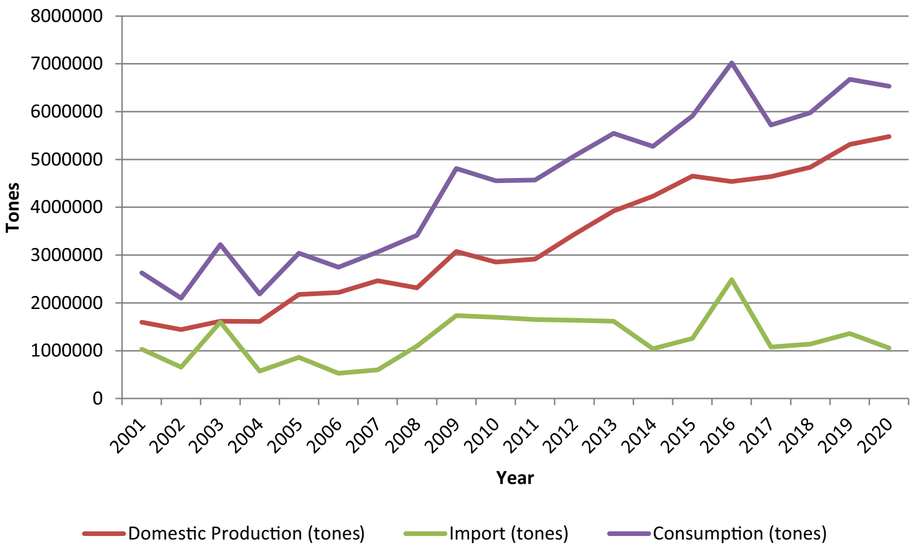


Fig. 3 Official data of wheat production, consumption, and imports in Ethiopia from 2001 to 2020 (FAOSTAT, 2022)

commodities such as coffee, live animals, and other commodities is spent back on importing wheat for food. This makes Ethiopian agricultural commodities mutually exclusive in terms of the foreign trade balance. Scientists unanimously agree on the fact that Ethiopian agricultural trade imbalance in general and that of wheat is unbearably negative, while the nation has untapped potential for wheat production either through irrigation or a rain-fed system.

4.4 Validation and proof of concept for irrigated wheat initiative in Ethiopia

In the past couple of years, the Federal Democratic Republic of Ethiopia, through the Ministry of Agriculture (MoA), undertook lowland irrigated wheat field trials to validate and generate proof of the concept of the feasibility of irrigated wheat production following the Awash River basin in the pastoral production and agro-pastoral system of Afar National Regional State, Ethiopia (Table 4). Prior to the start of this landmark trial, wheat was never cultivated in the lowlands of Ethiopia, despite a huge expanse of arable land.

To this end, the Ethiopian Institute of Agricultural Research (EIAR) was mandated to lead the field trial, generate proof of the concept for future intervention, identify suitable wheat varieties for the lowland irrigated system, and generate baseline information and data for future intervention.

The trials provided not only proof of concept on the possibility of irrigated wheat production but also verified the fact that productivity can be increased by 33–50% as compared to the rain-fed system (Table 4). However, in the lowlands of the country, the initiative suffered some setbacks in terms of sustainability and scalability due to a lack of experience by the pastoral and agro-pastoral systems. Subsequently, the irrigated wheat initiative was pulled back to its natural niche (mid and highland ecologies) as of the 2019/20 cropping season, with Oromia State chosen as the epicenter of the intervention, reserving the water surplus and the potential eastern and southwestern lowlands for later intervention.

4.5 Irrigated wheat initiative in Oromia regional state

Oromia Regional State is the largest state in Ethiopia. It is situated in a strategically and geographically important position in the country with an abundant natural resource base, strongly built institutions, and a high level of leadership commitment.

Table 4 Trends of irrigated wheat production between 2012/13 and 2019/20 in Awash River Basin, Afar Regional State, Ethiopia. *Source*: Data collected and compiled by the Ethiopian Agricultural Transformation Institute (ATI)

Year	Area covered (ha)	Productivity (t/ha)	Total production (ton)
2012/13	1	2.9	2.9
2013/14	3	3.87	11.6
2014/15	30	4.2	126.0
2015/16	58	3.68	213.7
2016/17	109	2.91	316.7
2017/18	804	3.77	3,029.8
2018/19	3,502	4.4	15,400.0
2019/20	12,500	4.128	51,600

Table 5 Outcome of "The Adama Declaration 2019" in Oromia National Regional State, Ethiopia

Year	No of districts involved	Area of production (ha)	Yield (Qtls)	Productivity (Qtls/ha)
2019/20	16	3,380.00	129,947.00	38.44
2020/21	226	382,237.00	11,796,584.80	30.86
2021/22	259	669,003.00	26,760,120.00	40.00

Table 6 National irrigated wheat field trial results

Year	Area cultivated	Area harvested (ha)	Production (Qtls)	Productivity (tones/ha)
2019/20	18,498.00	17,398.00	408,367.10	41.28[©]
2020/21	187,525.00	172,387.4	7,044,221.42	41.18
2021/22	709,735.5	674,626.5	25,251,109.00	37.43
Overall average	39.96			

[©]This data is only from 12,500 ha of controlled experimental fields. Data from other irrigated wheat are unavailable

The state launched the first region-wide irrigated wheat initiative in the presence of key stakeholders in Adama Town in 2019/20 and named the campaign "The Adama Declaration 2019". "The Adama Declaration 2019" was soon followed by the establishment of a task force for implementing regional responsibilities. Members of the taskforce included subject matter specialists, experts, regional steering and technical committees, and various stakeholders at the regional level. Simultaneously, field trials were conducted to fit wheat varieties to the environment, and resource mobilization for the scheme was also done. Regional and national agricultural research centers, higher learning institutions, the private sector, and other relevant stakeholders were assigned to spearhead the campaign for irrigated wheat production by clustering the regions into intervention zones with team leaders and coordinators assigned. The outcome of "The Adama Declaration 2019" in Oromia is depicted in Table 5.

Moreover, other small-scale campaigns of irrigated wheat production also took place in other regions such as Amhara, the Southern Nations and Nationalities and People's Region (SNNPR), Afar, and Somali Regional States, with Oromia State taking the lion's share with 92% of the total land covered by irrigated wheat, while the remaining four regions jointly contributed the remaining 8% (ATI, 2021) (Table 6). One of the limitations of the irrigated wheat initiative is the lack of uniformity and/or unavailability of reliable data, attributed to a lack of a well-organized data capture system and the absence of a centralized database platform (Tables 5 and 6).

5 Key drivers for successful adoption of the irrigated wheat initiative in Ethiopia

The major goal of the new irrigated wheat initiative is to address the various paths that contribute to achieving the objective of meeting Ethiopia's wheat demands and even producing surplus for export. Some of the factors that contributed to the perceived success of the irrigated wheat initiative included sustained input supply, cluster farming, intensive training of wheat farmers by subject matter specialists and experts, extensive variety trials to identify suitable varieties for specific agro-ecological zones, conducive policy support, and the commitment of the government.

5.1 Agricultural inputs

To support the newly launched Homegrown Economic Reform in general and the irrigated wheat initiative in particular, the Federal Democratic Republic of Ethiopia has been making relentless efforts to support the initiative with consistent input supply such as different types of fertilizers, locally developed wheat varieties, agrochemicals, finance, and, to some extent, farm machinery (Table 7). Government funding has grown exponentially in the past three years and stimulated stakeholders and actors to get involved in irrigated wheat production.

Table 7 Resources allocated and trainings offered on the irrigated wheat initiatives of Ethiopia

Year	Item	Unit	Quantity distributed
2019/20	Fertilizer	Quintals	9,602.00
	Improved seed	Quintals	4,800.00
	Insecticides and herbicides,	Liters	1,880.00
	Tractors with accessories and chemical sprayers	No	24.00
	Financial resources	ETB	62,123,442.00
	*Training	Person	1,494.00
2020/21	Fertilizer	Quintals	21,125.00
	Improved seed	Quintals	12,216.00
	Insecticides and herbicides,	Liters	7795.20
	Tractors with accessories and chemical sprayers	No	97.00
	Financial resources	ETB	299,922,927.74
	*Training	Person	5923.00
2021/22	Fertilizer	Quintals	Mainly covered by regions
	Improved seed	Quintals	129,181.10
	Insecticides and herbicides,	Liters	
	Tractors with accessories and chemical sprayers	No	Covered by regions
	Financial resources	ETB	418,526,601.00
	*Training	Person	591,269.00

*Training include agricultural experts, development agents, farmers/pastoralists and agro-pastoralists and private investors

5.2 Cluster farming

Cluster farming and land consolidation are newly introduced farming practices in the irrigated wheat initiative in Ethiopia. The cluster farming approach is intended to group farmers together with adjacent farmlands of common interest groups for planting the same crop across the fields as well as for the distribution and utilization of shared resources that require collective decisions. Lessons learned from the current wheat cluster farming of Ethiopia certainly serve as a model to repeat the same model for other crops (Supplementary Fig. 1). The cluster farming system initiated under this project needs to be adopted as a progressive approach for other food crops by farmers that possess fragmented but adjacent farmlands. Moreover, though the approach encourages monoculture cropping, it seems to be one of the key drivers of the green revolution in Ethiopia and beyond.

5.3 Stakeholder training and consultative workshops

Adoption of a new approach is a dynamic process that moves from learning to embracing and results in a population that can be categorized into adopters and non-adopters (Jabbar et al., 1998). On the other hand, farmers' changes in technology use and adoption are influenced by technical training, meetings, oral presentations, trust in technicians, and their belief level in technology (Chi & Yamada, 2002). Successful adoption of the current irrigated wheat initiative in Ethiopia has stemmed from continuous access to agricultural inputs, financial support, the provision of tax-free agricultural machinery and inputs, supportive policy frameworks, continuous stakeholder training and workshops, access to the market, and committed leadership. In this initiative, the government has provided intensive training for effective execution, of the initiative where the number of trainees increased from 1494 in 2021/20 to 591,269 in 2021/22 (Table 7). Furthermore, the initiative received the attention of the national mass media and has been extensively aired to convince the wider public to adopt the new initiative.

5.4 Screening appropriate wheat varieties

Multi-location field trials were conducted to screen and identify locally developed wheat varieties for irrigated wheat production. This has been one of the fundamental success factors of the initiative. In addition to bearing various other responsibilities of agricultural research and development, the Ethiopian Institute of Agricultural Research (EIAR) and Regional Agricultural Research Centers (RARI') were given the mandate to undertake multi-location field trials on agronomic practices and adaptation for 24 locally developed wheat varieties to match varieties to the environment.

5.5 Agricultural mechanization

Ethiopian agriculture, although the dominant sector of the economy, is constrained by age-old traditional production practices and policy problems. To realize rapid agricultural transformation and ensure food security in the country, the government has made two critical policy reforms, including the declaration of tax-free imports for agricultural machinery and inputs and the establishment of a new tractor assembly plant in Oromia

Regional State. The two major policy reforms have served as key drivers for the current agricultural transformation of the country in general and the irrigated wheat initiative in particular.

5.6 Institutional reforms and leadership commitments

Following the recent Homegrown Economic Reform launched by the Federal Democratic Republic of Ethiopia, the Ministry of Agriculture (MoA) has made a significant institutional reform by eliminating the long-standing bureaucratic institutional setup among sectors into a more robust, productive, and collaborative partnership that collectively contributes to a common goal, i.e., agricultural transformation and food security.

The structural reform made by top leadership in the Ministry of Agriculture (MoA) formed a common playing ground for all development partners to apply locally generated and relevant agricultural technologies to drive the overall agricultural transformation.

6 Projected wheat export plan for Ethiopia

The lowest-to-medium case scenario projection has demonstrated that, with its new irrigated wheat initiative, Ethiopia has already attained wheat security and sooner or later emerges as a new wheat exporting nation in Africa (Tables 8 and 9; Figs. 4 and 5, respectively).

6.1 Assumption for the lowest-case wheat production scenario

Two case scenarios, which consider current contexts and official national data, were considered for the projected wheat export plan of Ethiopia: The first-case scenario takes the following assumptions:

- The official land size of 1,807,265 ha for the rain-fed wheat system and the current level of productivity (3 tons ha^{-1}) are taken as benchmarks for projection. Furthermore, it is assumed that productivity grows by 1.7% per annum and land size for extra wheat production grows by 2% per annum
- A national and global estimate of 2.5% for the human population growth rate of Ethiopia is assumed for projecting human population growth by 2030
- The current productivity report of 4 tons ha^{-1} for irrigated wheat is benchmarked, and irrigated land is assumed to grow by 2.5% per annum
- Considering various wheat consumption drivers (population growth, increasing income, booming agro-processing factories, etc.), consumption is assumed to grow by 5% per annum
- Land allocated for the short rainy season (*belg*) wheat production and level of productivity are held constant at 250,000 ha of land and 7.16 tons ha^{-1}, respectively (Table 8).

Table 8 Projected wheat production, consumption, and export by 2030 for lowest case scenario (Assumption: rainfed wheat system, irrigated system and domestic wheat consumption increase 2, 2.5 and 5%, respectively). *Source*: Authors' compilation and projection based on data from Central Statistical Authority (2019/20), Oromia Bureau of Agriculture, Ethiopian Agricultural Transformation Institute (ATI), global data and Ethiopian Institute of Agriculture (EIAR, unpublished)

Year	Projected human population growth	Projected increase in land size in rain-fed (ha) (2% per annum)	Projected productivity in rain-fed 1.7%) taking the current 3ton/ha)	Projected yield from rain-fed system (tones)	Land cultivated during short rainy season (ha)	Yield with productivity held constant (7.16 tones/ha)	Irrigated wheat land increase by 2.5% increase per annum)	Productivity of irrigated wheat (tones/ha)	Projected yield of irrigated wheat (tones)	Production (tones)	Consumption (tones) with 5% increase per annum	Surplus for export (tones)
2021	109,321,875	1,807,265	3	5,421,795	250,000	1,790,000	382,237	4	1,528,948	8,740,743	6,533,575	2,207,168
2022	112,125,000	1,843,410	3.05	5,624,245	250,000	1,790,000	669,003	4	2,676,012	10,090,257	6,860,254	3,230,003
2023	115,000,000	1,880,279	3.10	5,834,254	250,000	1,790,000	1,100,000	4	4,400,000	12,024,254	7,203,266	4,820,988
2024	117,875,000	1,917,884	3.16	6,052,105	250,000	1,790,000	1,127,500	4	4,510,000	12,352,105	7,563,430	4,788,675
2025	120,821,875	1,956,242	3.21	6,278,091	250,000	1,790,000	1,155,688	4	4,622,750	12,690,841	7,941,601	4,749,240
2026	123,842,421	1,995,367	3.26	6,512,515	250,000	1,790,000	1,184,580	4	4,738,319	13,040,833	8,338,681	4,702,152
2027	126,938,481	2,035,274	3.32	6,755,692	250,000	1,790,000	1,214,194	4	4,856,777	13,402,469	8,755,615	4,646,853
2028	130,111,943	2,075,979	3.38	7,007,950	250,000	1,790,000	1,244,549	4	4,978,196	13,776,146	9,193,396	4,582,750
2029	133,364,741	2,117,499	3.43	7,269,626	250,000	1,790,000	1,275,663	4	5,102,651	14,162,277	9,653,066	4,509,211
2030	136,698,859	2,159,849	3.49	7,541,074	250,000	1,790,000	1,307,554	4	5,230,217	14,561,292	10,135,719	4,425,572

Table 9 Projected wheat production, consumption, and export by 2030 for medium case scenario (Assumption: rainfed system, irrigated system and domestic wheat consumption increase by 2, 5 and 10% per annum, respectively). *Source*: Authors' compilation and projection based on data from Central Statistical Authority (2019/20), Oromia Bureau of Agriculture and Natural Resources, Agricultural Transformation Institute (ATI) and Ethiopian Institute of Agriculture report (EIAR, 2022)

Year	Projected human population growth	Projected increase in land size in rain-fed (ha) (2% per annum)	Projected productivity in rain-fed 1.7%) taking the current 3ton/ha)	Projected Production in rain-fed (tones)	Land cultivated during short rainy season (ha)	Yield of short rainy keeping productivity at 7.16 tones/ha	Irrigated wheat land increase by 5% per annum	Productivity of irrigated wheat (tones/ha)	Yield of irrigated wheat (tones)	Production (tones)	Consumption (tones) with 10% increase per annum	Surplus for export (tones)
2021	109,321,875	1,807,265	3	5,421,795	250,000	1,790,000	382,237	4	1,528,948	8,740,743	6,533,575	2,207,168
2022	112,125,000	1,843,410	3.05	5,624,245	250,000	1,790,000	674,626	4	2,698,504	10,112,749	7,186,933	2,925,816
2023	115,000,000	1,880,279	3.10	5,834,254	250,000	1,790,000	1,320,000	4	5,280,000	12,904,254	7,905,626	4,998,628
2024	117,875,000	1,917,884	3.16	6,052,105	250,000	1,790,000	1,386,000	4	5,544,000	13,386,105	8,696,188	4,689,917
2025	120,821,875	1,956,242	3.21	6,278,091	250,000	1,790,000	1,455,300	4	5,821,200	13,889,291	9,565,807	4,323,484
2026	123,842,421	1,995,367	3.26	6,512,515	250,000	1,790,000	1,528,065	4	6,112,260	14,414,775	10,522,388	3,892,387
2027	126,938,481	2,035,274	3.32	6,755,692	250,000	1,790,000	1,604,468	4	6,417,873	14,963,565	11,574,627	3,388,938
2028	130,111,943	2,075,979	3.38	7,007,950	250,000	1,790,000	1,684,692	4	6,738,767	15,536,716	12,732,089	2,804,627
2029	133,364,741	2,117,499	3.43	7,269,626	250,000	1,790,000	1,768,926	4	7,075,705	16,135,331	14,005,298	2,130,033
2030	136,698,859	2,159,849	3.49	7,541,074	250,000	1,790,000	1,857,373	4	7,429,490	16,760,564	15,405,828	1,354,736

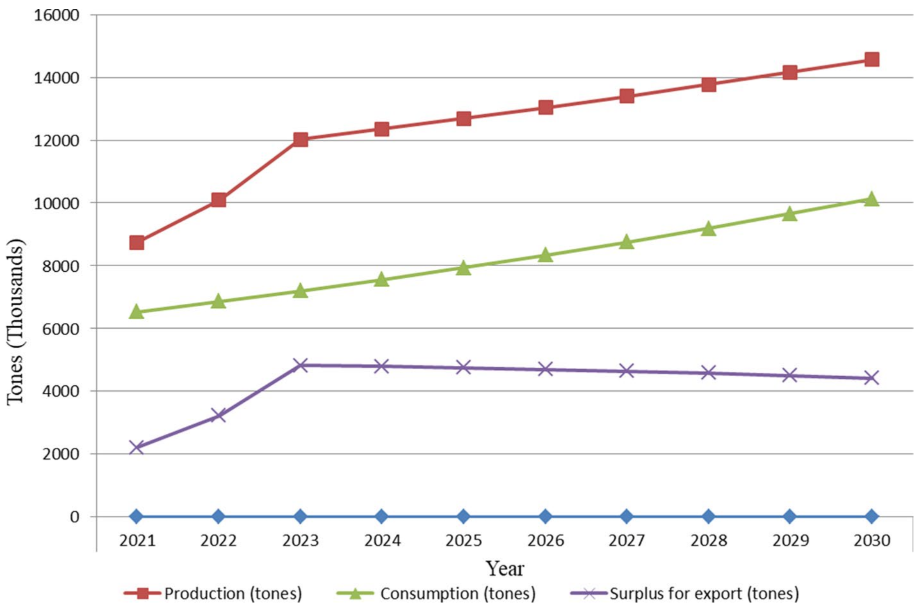


Fig. 4 Projected surplus wheat export from the irrigated wheat assuming lowest case scenario

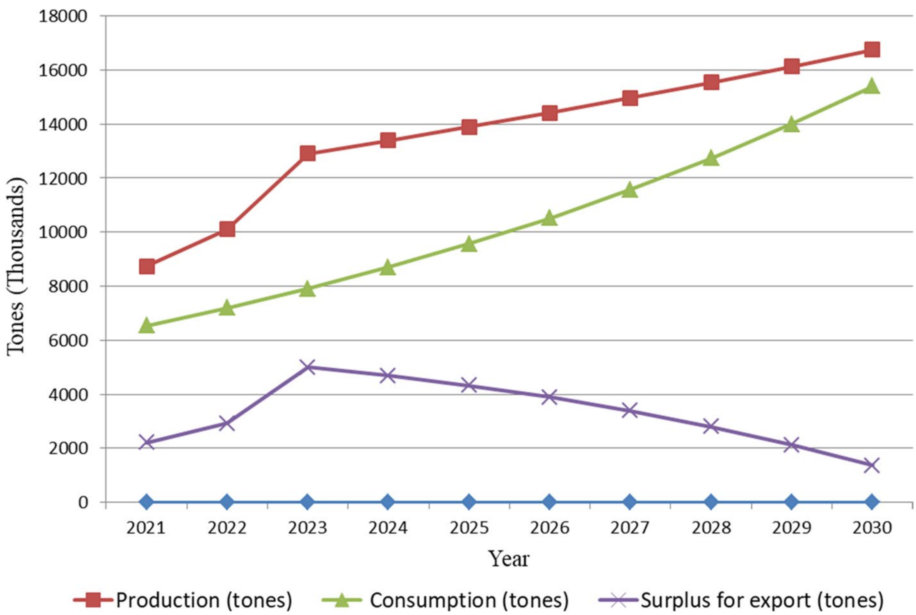


Fig. 5 Projected surplus wheat export from the irrigated wheat assuming medium case scenario

6.2 Assumption for the medium-case wheat production scenario

- The official land size of 1,807,265 ha for rain-fed wheat production and the current level of productivity (3 tons ha^{-1}) are taken as benchmarks for the projection. Furthermore, it is assumed that productivity grows by 1.7% per annum and land size for extra wheat production grows by 2% per annum
- A national and global estimate of 2.5% for the human population growth rate of Ethiopia is assumed for projecting the human population by 2030
- The current productivity report of 4 tons ha^{-1} for irrigated wheat is benchmarked, and irrigated land is assumed to grow by 5% per annum
- Considering various wheat consumption drivers (population growth, increasing income, booming agro-processing factories, etc.), consumption is assumed to grow by 10% per annum.
- Land allocated for short rainy season (*belg*) wheat production and level of productivity held constant at 250,000 ha of land and 7.16 tons ha^{-1}, respectively, as shown in Table 8.

7 Potential applications and implications

Based on the quantitative evidence and trends observed on the irrigated wheat initiative of Ethiopia, it can be concluded with absolute certainty that Ethiopia is not only ensuring wheat security in the short term but also emerging as one of the wheat-producing and exporting nations in Africa.

On the contrary, however, the increasing trend of wheat exports in the early years would not last longer. Exports will soon fall and show a declining trend over the years, driven by increasing domestic demand, low wheat productivity in both rain-fed and irrigated systems, a rapidly changing global climate, and competition with other agricultural commodities, particularly horticultural crops.

To overcome deficits in domestic wheat supply and remain competent in the regional and global wheat market, the irrigated wheat initiative of Ethiopia must be harnessed with fully functional farm machinery and accessories, robust and improved agricultural technologies and innovations that increase production and productivity per unit area, an efficient water management system, the development of a centralized database, seed system development, the engagement of the private sector, and the expansion of wheat fields to areas affected by soil acidity.

Success stories and lessons learned from the irrigated wheat initiative can be repeated in newly emerging agricultural initiatives such as horticulture cluster farming and the Livestock Development Initiative, locally known as the "*Yelemat Tirufat,*" which focuses on enhancing livestock production and productivity through village-based interventions for selected livestock commodities such as red meat, poultry, and dairy development.

8 Discussion

8.1 Potential limitations for sustainability

The sustainability and effectiveness of the irrigated wheat initiative of Ethiopia and its goal to reach overall wheat self-sufficiency are directly or indirectly affected by the following major factors.

8.1.1 Efficient water management system

According to a Malabo Montpellier Panel Report (2018), most of the African continent has only one growing season, and farmers have thus been vulnerable to erratic rainfall patterns and droughts that result in low yields and income. This particularly holds true for Ethiopia, where agricultural practice is mainly dependent on rainwater. Irrigated agriculture through efficient use of water resources and the development of irrigation schemes and efficient irrigation technologies is widely recommended. It is also important to learn from what other top wheat-producing African countries (Egypt and South Africa) have done right in terms of irrigated wheat, and adopting those efficient technologies will certainly lead to a successful irrigated wheat initiative in Ethiopia.

Unlike any other time, water has appeared to be one of the scarcest resources in the past three years in Ethiopia. A case example is that the largest and longest-running Awash River has dried up within a radius of 100 km of its source, attributed to inefficient water use through surface irrigation and inappropriate water management. It is time to put in place all available and robust irrigation technologies that maximize water use efficiency. This warrants considerable public sector investment to develop modern and efficient irrigation schemes, maintain and repair existing schemes, and deploy heavy-duty water pumps that increase water use efficiency.

8.1.2 Private sector engagement

Despite large government and donor-funded expenditures on the development of irrigation infrastructure in Ethiopia, its potential has not been fully realized. As stated in the Malabo Montpellier Panel Report (2018), the participation of private investors in irrigation infrastructure development can make a good business: yields from irrigated crops are twice or more than those from rain-fed crops in Africa, where the benefits of expanding areas under irrigation are estimated to be twice as much as the costs.

Irrigation also offers opportunities for new and innovative models of public–private partnerships (PPPs), while governments are key to creating investment-friendly environments. Engagement of the private sector in irrigated wheat production has multiple benefits. On one hand, they engage in profitable irrigated wheat production themselves. On the other hand, the private sector is a source of more advanced and smart irrigation technologies and systems that have spillover effects on smallholder farmers. Therefore, it is essential to attract private investors into the irrigated wheat initiatives by providing them with financial securities, smart subsidies, or tax waivers to promote engagement with smallholders.

8.1.3 Establish a centralized database platform

Sustainability and scalability of the irrigated wheat initiative require a uniform, hierarchically organized, and centrally managed database platform. However, data on the irrigated wheat initiative of Ethiopia was collected by different institutions and was thus less uniform and inconsistent in the parameters collected. For instance, the data used in this paper were collected from different institutions, such as the Ethiopian Agricultural Transformation Institute (ATI), the Ethiopian Institute of Agricultural Research (EIAR), and the Oromia National Regional State Bureau of Agriculture, which themselves have no structured and uniform data management system. Therefore, the establishment of a centralized national database platform and other valuable tools such as artificial intelligence need to be developed to record accurate and uniform data across institutions to make evidence-based decisions by policymakers and development planners. Furthermore, as wheat is highly susceptible to various fungal and bacterial diseases, automatic disease detection systems using unmanned aerial vehicles (UAV) serve as powerful tools to control diseases, as described in Ali et al. (2023).

8.1.4 Seed system development

As seed is a great vehicle of change and is considered a driver for agricultural transformation, all agricultural ventures must start with seed. However, other inputs and better management practices are also needed (ATO, 2020). The seed system involves two major distinct activities: breeding and seed production activities (Ejeta, 2013).

With the current irrigated wheat initiative in Ethiopia, the sustainable supply of improved and suitable seed under specific wheat production environments appears to be one of the major limiting factors. It is apparent that the national and regional seed companies and enterprises mandated to multiply and distribute improved wheat varieties are struggling to cope with the current seed demand of the country. Therefore, the current shortage of improved wheat seed calls for sustainable and speedy niche-specific varietal development by the National Agricultural Research System (NARS), strengthening of formal seed multipliers (regional seed enterprises and private seed companies), and informal seed multipliers (contract farming) by organizing interested farmers into a seed multiplying unit.

9 Conclusion and the way forward

Evidence shows that several efforts have been made by a consortium of international donors, in collaboration with national governments, to replicate the Asian Green Revolution in Africa. However, impact assessments of such interventions, for instance, interventions by AGRA, have shown that organizations' efforts to bring the Asan Green Revolution to Africa have failed because little attention has been given to finding local solutions for local problems and the perception of one-fit-all. Even agricultural development models and intervention strategies that work well for one country hardly work for another in Africa. Therefore, it would have been better to give special attention to local peculiarities since Africa is endowed with diverse climates, diverse farming systems, diverse food and nutritional habits and is a home for complex socio-economic and socio-cultural setups.

In the middle of a controversial AGRA evaluation report, Ethiopia launched a new national development reform known as the Homegrown Economic Reform, aimed at finding local solutions to local problems. One of the reforms where Ethiopia has made an increasingly significant leap forward was in the agricultural development sector, where its irrigated wheat initiative received a top national priority. With the new agricultural development paradigm, Ethiopia has not only attained wheat self-sufficiency in a very short period but also demonstrated the possibility of replicating the Asian Green Revolution in Africa.

However, policymakers and development planners need to be cautious of the negative long-term environmental impacts of large-scale irrigated wheat campaigns in Ethiopia. Environmentalists and right groups have already warned that the irrigated wheat campaign in Ethiopia is gradually leading to the buildup of soil salinity in the lowlands and the loss of crop biodiversity in the highlands, while conflicts over the equitable use of water resources between upstream and downstream communities are highly likely. Therefore, sooner or later, the government must install proper irrigation schemes to minimize environmental damage and establish a regulatory framework for equitable use of water resources to sustain and scale up the irrigated wheat initiative.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10668-023-03961-z.

Acknowledgements The authors are grateful to Oromia Bureau of Agriculture (OBA), Agricultural Transformation Institute (ATI) and the Ethiopian Institute of Agricultural Research (EIAR) for providing primary data and information on the irrigated wheat production initiatives in Ethiopia.

Funding The authors did not receive specific support or funding from any organization for the submitted work.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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