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Abstract

With less than a decade to go, the implementation of the Sustainable Development Goals on water, nutrition and food security is currently off-track. To address the mounting problems of water scarcity and malnutrition, we need a strategy to assist farmers to produce staples for basic food security while, at the same time, increasing the production of high-value and nutrient-dense crops.

This report investigates the relationship between water and nutrition using data from Ethiopia on yield, water productivity, and the macro and micronutrient contents of foods. Ethiopia is challenged by erratic rainfall and dry spells. With limited capacity to cope with risks, smallholder farmers concentrate on staple crops, chiefly maize, teff, pulses and oilseeds. Low yields, low water productivity, and a lack of diversification of cropping patterns have had severe consequences for food security and nutrition.

The report uses a nutritional water productivity (NWP) framework to interpret the relationship between nutrition and water in the context of water challenges. It argues that higher yields – of both staple and nutritious crops – are possible, even in water-stressed areas. This will require an agricultural transformation that ensures that efforts to enhance water productivity are linked to the promotion of healthy diets. Increasing water productivity and stabilizing yields at realistic levels will also be crucial to increasing the resilience of farmers. Better coordination and timing of water and other inputs, notably fertilizers and improved seeds, is likely to enhance productivity and to reduce the threats of a further encroachment of agriculture into other ecosystems. A diversified production system is required for food security, nutrition and poverty alleviation. There is an opportunity to provide strategic support for crops and other farm produce with high economic and nutritional value. A range of crops and other produce can be included in farming systems ranging from rainfed to irrigated agriculture. For the farmers to be stimulated and able to capitalize on the increasing need and demand for such produce, the development of markets, and associated investments in cold storage, roads/transport and food procurement programmes that prioritize nutritious produce will be key.

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1. Background and context

1.1 FOOD, NUTRITION AND WATER CHALLENGES AND TRENDS

Malnutrition is a global problem with severe health and economic ramifications; it directly impacts one in three people around the world.[1] Malnutrition is exacerbated by water scarcity, with about 30 percent of the world's population living in water-stressed environments. Over the next twenty years, water scarcity and malnutrition are expected to affect half of the world's population, an estimated 4.8 billion people (Ringler *et al.*, 2016). Meanwhile, widespread undernutrition exists alongside an increasing prevalence of overweight, obesity, and micronutrient deficiencies.

A gap between actual and recommended diets is universal and associated with avoidable ill health and premature death, as well as incurring enormous economic and societal costs. Worldwide, 151 million children are stunted; 51 million children suffer from wasting and more than two billion people are micronutrient deficient (see, for example, UNSCN, 2019). The pervasiveness of diet-related non-communicable diseases is increasing, including coronary heart disease, stroke and diabetes, with 2.1 billion adults characterized

1 Malnutrition refers to the implications of undernourishment, overweight and obesity, and micronutrient deficiency (FAO/ENS, 2013).

as overweight or obese. In the past 30 years, the global prevalence of diabetes has almost doubled (Willett *et al.*, 2019). Global estimates suggest that malnutrition – in all of its forms – costs society up to USD 3.5 trillion per year, with overweight and obesity alone costing USD 500 billion per year (The Global Panel, 2016).

It is a paradox that increased malnutrition has run in parallel with an unprecedented growth in the production and supply of food. Based on data compiled from FAO's Food Balance Sheets, the global supply of food per capita, in terms of caloric content, increased by about 30 percent from the beginning of the 1960s to the beginning of the 2010s. During this period, the world population increased from around 3 to 7 billion (Lundqvist and Unver, 2018). Similarly, protein supply showed a significant per capita increase during the same years in low- and middle-income countries (FAO, 2017). A reduction in the unit cost of food production fueled this change in many parts of the world (Pinstrup-Andersen, 2018). An anticipated continuous income growth is expected to counter some of the effects of climate change on global food production trends and associated nutrition security (Nelson *et al.*, 2018). However, given a lack of effective policies, the prevalence of micronutrient deficiencies is expected to continue (Nelson *et al.;* 2018, Willet *et al.,* 2019).

After decades of gradual decline, the number of people suffering from hunger is on the rise. Conflict, displacement and popular uprisings are major reasons behind the recent increases in undernourishment (FAO *et al.,* 2018). Several of the SDGs and their targets are not on track for achievement, notably SDG 2 (end hunger, improve food security and nutrition and promote sustainable agriculture), and SDG 6, Target 4 (substantially increase water use efficiency across all sectors) (FAO *et al.,* 2019; UNSCN, 2019). Agriculture is the largest user of fresh water. The transformation of agriculture and the achievement of the SDGs thus hinge on improving the management and productive use of water resources.

Climate variability and uncertain rainfall can lead to malnutrition if they discourage farmers from intensifying and diversifying their production. Erratic rainfall, with dry spells and unpredictability at the onset of the cultivation season, is also a reality in areas where average annual rainfall is high (Erkossa *et al.,*2019). Inefficient harnessing of rainfall and flash floods and poor management of water, from 'the-rain-to-the-drain,' contribute to reduced yields and low productivity. A poor coordination of inputs in agriculture contribute to the gap between potential and actual yields, Global Yield Gap Atlas: www.yieldgap.org/gygamaps/app/index.html.

With continuing demographic changes and increasing income, at least among some segments of the population, demands for more food and changes in food preferences are inevitable. Given the high levels of malnutrition, there is a growing recognition of the need for diets that can reduce imbalances in the availability of different nutrients (Willet *et al.*, 2019). Several authors highlight the need for micronutrients (Nelson *et al.*, 2018; Pinstrup-Andersen, 2018). Strategies around food security and nutrition must also recognize the danger of continuing to expand agriculture into other ecosystems. Concerns about growing competition and the variability of water resources and associated risks[2] demand actions that address both nutrition and erractic rainfall concerns.

[2] See, for example, World Economic Forum: http://reports.weforum.org/global-risks-2018/global-risks-landscape-2018/#landscape.

1.2 UNTAPPED OPPORTUNITIES

Smallholder farmers will not readily switch from the production of starchy staples to crops with a high density of essential nutrients, not only because they are familiar with cultivating these crops, but also because they are important for their basic food requirements and comparatively less risky than many more nutritious and economically valuable crops. By increasing and stabilizing yields and improving water productivity, farmers might be motivated to grow more nutritious crops. Better access to remunerative markets and links to public procurement programmes could also be important drivers.

Any effort to promote the transformation of agriculture requires particular attention to three key issues:

- Based on a large set of data from six countries in Africa, Sheahan and Barret (2018) have shown that farmers in Africa use more irrigation, fertilizers and quality seeds of improved varieties than expressed in statistical information and understood by conventional wisdom. But the coordination of these inputs is poor, even at the plot level. *Ensuring better coordination and timing of existing inputs is likely to give a boost to yields, water productivity and income and could stimulate the cultivation of high-value crops, including nutritious crops, using the same amounts of inputs* (see Chapters 4 and 5).
- *Significant increases in total production and yields can be achieved by adding small amounts of water at critical points in a season, e.g. through supplementary water provision in rainfed systems* (Rockström and Barron, 2007; Molden, 2007). The opportunities for high marginal productivity increases are especially promising in areas where yields are low and variable. Simple irrigation systems that can be built and controlled by farmers themselves and/or with limited technical and other support may stimulate the cultivation of high-value crops (Lefore *et al.*, 2019; Bryan *et al.*, 2019) (see Chapters 4 and 5).
- On the demand side, high and stable economic growth rates, often between 5 and 10 percent in many developing countries, combined with demographic and socio-economic changes, mean greater opportunities for farmers to sell to consumers in growing urban centres, as well as to industry and other farmers, e.g. in agroecological zones with differences in cropping patterns. *The combination of public procurement programmes and the development of marketing channels are important drivers in the intensification and transformation of agriculture.* Such programmes and markets demand staple crops, e.g. wheat and maize, but also nutritious and economically valuable crops (see Chapter 6).

1.3 WATER AND THE SUSTAINABLE DEVELOPMENT GOALS (SDGs): COORDINATING SECTOR POLICIES AND ACTIVITIES

Target 6.4 of the SDGs relates to the efficient use of water across all sectors, including sustainable withdrawals and supply, while SDG 2 is about ending hunger, achieving food security and improved nutrition, and promoting sustainable agriculture. The two goals are closely linked: in both cases, challenges include achieving efficiency in harnessing and managing water and enabling its use in ways that effectively promote agricultural improvements, e.g. to reduce malnutrition. There is a potential synergy to be gained from a coordination of interventions within and across different water-dependent sectors. For example, using more water to produce crops with a high density of essential nutrients is of paramount importance. If such efforts are coordinated with improvements in access to safe and affordable drinking water for all (SDG 6.1) and safe sanitation arrangements and hygiene (SDG 6.2), the prevalence of diarrhoea and other infections is likely to be reduced and the absorption by the body of important nutrients improved, thus achieving nutrition outcomes in line with SDG 2 (UNSCN, 2019; Swaminathan and Bhavani, 2013).

2. Introduction to the study

This study is based on the premise that smallholders will normally favour crops that are important for their basic food security and that involve relatively low levels of risk. Our assumption is that increasing water productivity and reducing yield gap can pave the way to a diversification in cropping patterns and environmentally-sound food systems that benefit both farmers and society.

While this assumption rings true, little has been done to test its validity. This is partly due to the tendency within the research community and development agencies to work in silos. Although water and nutrition are inherently related, work in the two sectors has developed in parallel, using different approaches and with limited coordination. Agricultural water professionals, for example, have approached the subject of water and food production in water-scarce regions from the perspectives of water productivity and water use efficiency (Descheemaeker *et al.*, 2013; Mutema *et al.*, 2019). For their part, nutritionists have measured the nutritional balance of global food production by comparing the recommended nutritional diet to global agricultural production statistics (Bahadur *et al.*, 2018). If carried out in isolation, these approaches will always miss important opportunities for synergy; they need to be brought together to achieve the goal of producing more nutritious food with available water resources.

In this regard, nutritional water productivity (NWP) has been recognized as a useful metric for quantifying the water-food-nutrition nexus, especially in water scarcity regions where food and nutrition insecurity are prevalent, such as South Asia and sub-Saharan Africa (Chibarabada *et al.*, 2017). The NWP framework, developed by Renault and Wallender (2000) and first applied to data from California, illustrates that switching from calculations of productivity per unit of land to calculations of productivity per unit of water could play a vital role in supporting efforts to cope with additional requirements for food and the growing competition for uncertain water resources.

This study uses the NWP framework to interpret the relationship between nutrition and water in the context of Ethiopia's water challenges and to determine whether higher yields – of both staple and nutritious crops – are possible, even in water-stressed areas.

The choice of Ethiopia was motivated by government initiatives around nutrition, including the Seqota Declaration (https://gtn-learning.org/sites/default/files/library/2019-08/SD 20presentation%20-%20Progress%20update%2C%20Challenges%20and%20Lessons%20July%2011%202019_0.pdf), which was launched in 2015 with the aim of ending undernutrition in Ethiopia by 2030. A number of documents describe Ethiopia's Nutrition Sensitive Agriculture Strategy (https://cdsfethiopian.com/nutrition-sensitive-agriculture/; www.eiar.gov.et/index.php/agricultural-growth-programme-ii), whose aim is to "contribute to improving the nutritional status of children and women by increasing the quantity and quality of available, accessible and affordable food and promoting the use of diverse, nutritious and safe foods by all Ethiopians at all times." The strategy initiative was evaluated in mid-2019 and the preliminary findings prompted slight improvements in the Agricultural Growth Programme II/AGP II (PSI, 2019).

Secondary data and information from Ethiopia were used to test the applicability of the NWP framework. NWP indicators were calculated for water productivity of the macro and micronutrient content of crops produced in Ethiopia. The availability and reliability of data and the validity of assumptions are of prime importance for this analysis. Although information on rainfall and crop yields are typically available, data on agricultural water withdrawal and use by crop, as well as associated nutrition outcomes, remain scarce. Nutrition density and nutritional water productivity vary by species and at different points along the production chain. For example, the nutritional and economic value of perishable crops and animal-sourced food may deteriorate rapidly after harvest, depending on transport and storage. It is also important to recognize that the production of animal feed is not fully interchangeable with the production of crops for direct human use. Typically, the water transpired and evaporated from grazing areas cannot be used to produce crops for humans to eat.

BOX 1

Key concepts in nutritional water productivity (NWP) analysis

- *Water productivity* in agriculture is the ratio between a unit of output (weight or economic value) and a unit of water input, e.g. harvested amounts of crops obtained in relation to a given water input, which can be estimated, for example, as evapotranspiration, i.e., the consumptive use of water during a season.
- *Nutritional water productivity* is the output of production in terms of the nutritional density of a crop per volume of water input (Renault and Wallender, 2000).
- *Nutrition density* refers to the relative amounts of macro and micronutrients in a crop, measured in grams, milligrams, micrograms and kcal per 100-gram crop.
- *Nutrition security* is secure access to an appropriately nutritious diet coupled with a sanitary environment, adequate health services and care to ensure a healthy and active life for all household members. Nutrition security differs from food security in that it also considers the aspects of adequate caring practices, health and hygiene in addition to dietary adequacy (FAO, IFAD and WFP, 2013).
- *Nutrition-sensitive agriculture* is sensitive to the incorporation of nutrition objectives, concerns and considerations (FAO/ESN, 2013).
- *Dietary diversity* measures the variety of food from different food groups over a reference period (FAO, 2010).
- *Sustainable healthy diets* promote all dimensions of individual health and wellbeing; have low environmental pressure and impact; are accessible, affordable, safe and equitable; and are culturally acceptable. The aims of sustainable healthy diets are to: help prevent all forms of malnutrition (i.e. undernutrition, micronutrient deficiency, overweight and obesity); reduce the risk of diet-related non-communicable diseases; and support the preservation of biodiversity and planetary health (FAO and WHO, 2018).

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3. Water, agriculture, food security and nutrition and related policy initiatives in Ethiopia – an overview

3.1 SMALLHOLDER FARMERS, LOW YIELDS AND LITTLE MARKETABLE SURPLUS

There are 12 million smallholder households in Ethiopia, comprising around 89 million people. Only about 40 percent of Ethiopian farmers cultivate more than 0.9 hectares and these smallholders who own relatively larger farm-size account for three-quarters of the total cultivated area (Seyoum Taffesse *et al.,* 2011.; CSA, 2018). The combination of farming and the rearing of livestock is common.[3] Livestock rearing is significant, with about 50 million cattle and poultry, and 20 million sheep and goats, respectively; The area occupied by permanent pasture is larger than that of cultivated land (FAO, 2016). For various reasons,

[3] Estimates of the number of livestock owner are similar to the number of smallholders. It is reported that pastoralists are increasingly involved in farming and non-farming/non-pastoral activities (http://fes-ethiopia.org/274; Tsegaye, et al., 2013; ILCA, 1993).

most farmers concentrate on producing just one or two crops. A survey for the Agricultural Growth Project shows that a large majority of farmers produce mostly starchy staples, predominantly to cover the basic requirements of the family. Fewer than 10 percent of households produce three or more crops (Wakeyo *et al*., 2018).

On average, cereals were grown on almost three-quarters of total cultivated area over a three-year period from 2004/05–2007/08. Smallholders produce a yearly average of 26.8 million tonnes of cereals, which is about two-thirds of total agricultural production in terms of weight (CSA, 2018). With the average yield of cereals ranging from 1.7 to 3.7 tonnes/hectare (CSA, 2018), the average total production per smallholder household is low, or about 2 tonnes during the main cropping season. Given erratic rainfalls, a serious depletion of soil fertility and poor management, yields can be much lower than the average figures suggest, e.g. for maize production in the upper Nile Basin (Erkossa *et al.*, 2011). Low yields, the high variability in rainfall and risks of drought and moisture stress contribute to a lack of crop diversification and the associated lack of a surplus, even in areas with good agricultural potential (Wakeyo *et al.*, 2018).[4]

Data from the Ethiopia Central Statistical Agency (CSA) indicate that yields increased for all crops between 2001 and 2017. Yet, there is low or no surplus from agriculture, income for farmers is low, and industry finds it difficult to run at full capacity when both the quantity and quality of produce do not meet food processing and consumer expectations. A high dependence on imports of food and agricultural commodities is a natural consequence of low agricultural productivity (FAO, 2019). The increasing dependence on food imports, with heavy drains on foreign exchange, is a threat in many parts of Africa (Abrams, 2019).

Government strategies and policies highlight the need for Ethiopia's agricultural transformation. The goal is for farmers to adopt modern, intensive agricultural practices (IFDC, 2015). In addition to increasing the area equipped for irrigation, promoting the use of mineral fertilizers and improved seeds is an essential component of the country's agricultural transformation policy. For a number of years, the sales, distribution and use of mineral fertilizers, mainly DAP (diammonium phosphate, with a high content of nitrogen and phosphorous) and urea (NPK, with a high content of nitrogen), increased by about 6 percent per year. The use of these fertilizers is very widely practiced as a means to change agriculture in Ethiopia, according to data from the Central Statistical Agency (CSA, 2018).

However, there is limited information on the actual use and efficiency of fertilizers (IFDC, 2015). A lack of site-specific fertilization rates may be due to practical difficulties and a lack of education and proper fertilizer recommendations (Tamene *et al.*, 2017).[5] Combining mineral fertilizers with the cultivation of nitrogen fixating leguminous crops in a crop rotation system can promote yield increases in major crops. However, reliable information is lacking about the extent to which this combination is being used in Ethiopia (Atnaf *et al.*, 2015).

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4 These findings were prepared for the annexed result framework of the 2017 baseline report of the Agricultural Growth Programme Project II

5 A recent national soil testing programme conducted by the Ethiopian Agricultural Transformation Agency (ATA) revealed that most Ethiopian soils are deficient in several macro and micronutrients. See Gelaw *et al.* (2018).

In addition to productivity challenges in the agricultural sector,[6] limited access to credit and to lucrative markets discourage farmers from investing in agricultural improvements (FAO and WHO, 2018). Better market access and links to school feeding programmes and other public procurement initiatives that provide opportunities for farmers to increase their income could motivate them to diversify their cropping patterns to include crops with a high nutrient density, such as fruits, vegetables and leguminous crops.

3.2 RAPID ECONOMIC AND POPULATION GROWTH, ERRATIC RAINFALL AND OTHER WATER CHALLENGES

Ethiopia has one of the fastest growing economies in Africa. According to World Bank data, the average annual economic growth from 2007/08 to 2017/18 was 9.9 percent (www.worldbank.org/en/country/ethiopia/overview). Between 2004/05 and 2009/10, poverty, measured by head count index, declined from 38 percent to 28.2 percent.[7] Given a young, rapidly increasing population, urbanization, and strong, broad-based growth, the demand for water and food, among other things, is rising quickly in Ethiopia. The United Nations estimates that Ethiopia's population – currently 115 million – will reach 139 million by 2030.

Population growth implies a corresponding decrease in the availability of water and land per person (see Table 1). This calls for more, but also a greater variety, of food to meet growing demand, to reduce malnutrition and dependence on food imports. Improvements in water resources management in different geographical contexts and different times of year will be a critical factor in such a transformation of agriculture.

Table 1 presents the main trends addressed in this report. With a tropical monsoon climate, Ethiopia's rainfall varies significantly over time and geographically/topographically. Average rainfall is about 850 mm per year. Although data on the national scale suggest a relative abundance of water, all river basins – with the exception of the Nile Basin, which covers about one third of the area of Ethiopia – face water shortages (based on a 2011 European Union assessment, as quoted in FAO, 2016). Erratic rainfall and seasonal variation in precipitation and runoff are reflected in the lack of perennial rivers in the lowlands (FAO, 2016). The rainfall pattern appears to be fast becoming more erratic (Kiran *et al.*, 2018) and given its heavy dependence on rainfall, agriculture in Ethiopia is ever more vulnerable in terms of the high risks it presents to farmers (World Bank, 2006).

Low rainfall characterizes the eastern part of Ethiopia, where pastoralists dominate. Low rainfall is also found across a band in the central part of the country that stretches from north to west. High rainfall areas are found primarily in the west (Bekele *et al.*, 2010) and in highland areas, e.g. in the Blue Nile Basin (Erkossa *et al.*, 2019). Figures presenting a high annual, average rainfall and a large amount of renewable water resources per capita hide the fact that droughts, dry spells and seasonal water scarcity are experienced in areas with relatively abundant average annual rainfall (Kiran *et al.*, 2017; Erkossa *et al.*, 2011). Aside from 'normal' seasonal and inter-annual variation in precipitation, Ethiopia has faced a number of major droughts and related famines in recent decades, e.g. 1973-74, 1983-84, 1987-88, 1990-91, 1993-94 and 2015-16 (FAO, 2016).

[6] These include limited access to credit, low yields due to unpredictable and unreliable rainfalls, lack of adequate infrastructure, etc.

[7] Despite this sharp decline, about a quarter of the population still falls below the national poverty line (MoFED, 2010).

As previously noted, a range of efforts are being made to develop the agriculture sector in Ethiopia, with irrigation as a key component. According to a projection presented in Bekele *et al.* (2010), the expansion of irrigation could exceed five million hectares, initially with an emphasis on small-scale schemes and gradually including medium- and large-scale schemes. However, Bekele *et al.* also observed that the pace of project implementation has been poor.

TABLE 1
Trends in selected variables for Ethiopia, 1998/2002 – 2013/2017

Variable	1998-2002	2003-2007	2008-2012	2013-2017
Population (million) (a)	66 (2000)	74 (2007)	79.8 88 (2010)	105 (2017)
Permanent crops area (million ha) (b)	0.65	1.04	1.14	1.14
Cultivated area (arable land plus permanent crops) (million ha) (b)	10.5	15.08	16.49	16.26
Total renewable water resources (km3/year)	1 221	1 221	1 221	1 221
Total renewable water resources per capita (m3/cap, year) (b)	1 731	1 506	1 320	1 162
Agricultural water withdrawals as a percentage of total withdrawals (b)	93.6	89		91.8
Percentage of the cultivated area equipped for irrigation (b)	1.44	1.31	4.2	5.3
Stunting: percentage of children < 5 years (c)	65 (1990)			37 (2018)

Note: Permanent crops are grown over a long period of time, and do not require replanting for several years after each harvest. All fruit trees (i.e. oranges, mandarin, bananas, etc.) and trees for beverages (i.e. coffee, tea, hops, etc.) are considered permanent crops but meadows and pastures are not (CSA, 2017/18).
(a) Based on data from the Ethiopia Central Statistical Agency (CSA, 2013) and UN population statistics. The lower estimates for 2010 and 2017 are from the CSA while the higher estimates are from the UN. A census was carried out by CSA in 2007 and one was planned for 2017 but was not carried out.
(b) AQUASTAT: www.fao.org/aquastat/en/database
(c) https://ec.europa.eu/europeaid/ethiopia-nutrition-country-fiche-and-child-stunting-trends_en

Estimates around water and land resources, water use and plans for expanding irrigation vary widely. According to statistics in AQUASTAT, arable land area increased from about 10 to 15 Mha between 1998/2002 to 2013/2017 (see Table 1). Other estimates are much higher. According to Bekele *et al.* (2010), "estimates of the cultivable land area vary between 30 to 70 Mha. According to Table 1, only a small part of arable land is sown to permanent crops. To increase the validity of these figures, we would need information about soil fertility. Adimassu *et al.* (2018) summarize the magnitude of land degradation, soil and soil nutrient erosion, and their economic implications, in four regions of Ethiopia. Vast areas of fertile land have become unproductive. Soil nutrient depletion is severe and estimates suggest that this costs farmers about USD 4.3 billion per year.

Data on the actual implementation of irrigation schemes in Ethiopia are scarce (Eemeke, *et al.*, 2011; Awulachew *et al.*, 2010). There are indications, however, that the area actually irrigated is smaller than reported, and is less than the projected area included in Ethiopia's river basin master plans,[8] with differences between geographical and administrative districts (Kiran *et al.*, 2018). Consequently, estimates of the percentage

[8] Less ambitious plans are now more common, with a planned expansion of irrigation to 2.7 million hectares (FAO, 2016).

of the agricultural land currently under irrigation vary, from about 5 percent (as in Table 1), to 7–8 percent (Kiran *et al.*, 2019) to about 10–12 percent (Wakeyo *et al.*, 2016; Gutema *et al.*, 2017). In terms of total acreage, fewer than 100 000 hectares are under government-initiated irrigation. Figures on what is referred to as 'full-control' irrigation, spate irrigation (the harnessing of floodwater and water in inundated areas) and systems that are not, or only partly, operational are uncertain (FAO, 2016).

Investments in irrigation by federal and regional governments are nevertheless increasing, e.g., through the Agricultural Growth Programme (AGP). The AGP allocates funds to upgrade traditional schemes for irrigation, strengthening modern schemes and developing new small- and medium-scale irrigation schemes. The programme is expected to enable better harnessing of rainfall and a higher efficiency and flexibility in water use, including support for water harvesting and micro-irrigation systems (EIAR, 2019).

Plans for the expansion of irrigation will require additional water storage and withdrawals, from surface, ground and other sources, such as floodwaters. With a hypothetical expansion of irrigation to an additional 2.5 million hectares and a hypothetical average irrigation water duty of 400 mm per year, the additional withdrawal of water would amount to about 10 km^3 per year. Assuming that water use efficiency (conveyance, distribution, timing) is low, higher irrigation duties will be required to secure high yields. The extent to which expanding irrigation, and the associated increase in water storage and withdrawals, will cause water shortages in downstream segments of river basins Changes in basin water balance and/or other non-desirable consequences will naturally vary by geographic area.

Despite a rapid expansion of modern irrigation systems, many lack the effective management procedures, legal provisions and institutional arrangements required to function smoothly (FAO, 2016). Even if Ethiopia is successful implementing a rapid expansion of large, medium and small-scale irrigation, due to technical, cost and other constraints, most smallholder farmers will continue to depend on rain-fed practices, which are high risk and low yielding and vary from season to season and plot to plot. For these farmers, an effective strategy might be to develop micro- or household irrigation arrangements to supplement rainfall. Such a strategy could improve smallholder livelihoods while also making a better use of local rainfall.

Traditional irrigation schemes have existed in Ethiopia for centuries. Over time, a range of arrangements have been developed for providing supplementary water at household and community levels to counter erratic rainfall and stabilize and enhance yields. It is evident that smallholder farmers generally prefer subsistence crops to high-value cash crops (MoA, 2011). But there are signs that a diversification in cropping patterns becomes more likely with supplementary irrigation (FAO, 2016) and greater marketing opportunities. As discussed in Chapters 5 and 6, micro- or household irrigation to supplement predominantly rainfed agriculture can help increase yields and increases the likelihood that smallholders will decide to cultivate high-value crops, including crops with a high nutrition density. However, it is neither likely nor desirable that smallholder farmers abandon the cultivation of crops that involve relatively low risks and provide basic food security for the household.

3.3 LINKS BETWEEN FOOD PRODUCTION AND DIETS

Data compiled by FAO (e.g. FAO 2013) indicate that cereals are Ethiopia's most important crops, providing a relatively large share of energy in human diets, although limited amounts of other nutrients.. Maize dominates the food basket (about 30 percent), followed by wheat (20 percent) and teff (20 percent), with beans, peas or pulses serving as supplements. After cereals, pulses and oilseeds are the second and third most important crops in Ethiopia respectively, according to acreage. Pulses, vegetables, root crops and fruits are grown as monocultures in separate plots, in rotation or mixed with cereals. The mix is important for nutrition and for fertilizing the soil through N-fixation. However, a survey of national food habits showed that fewer than 10 percent of respondents followed a diet including foods other than cereals and grains (EPHI, 2013). The highest energy intake comes from carbohydrates. Limited dietary diversity, inadequate intake of fruit and vegetables, and insufficient intake of high-quality protein and micronutrients, particularly vitamin A and zinc, is evident in Ethiopia (Gebru *et al.*, 2018).

The poor nutritional status of women and children is persistent, with pervasive and severe micronutrient deficiency (Gebru *et al.*, 2018). The estimated micronutrient intake is below the recommended amounts for zinc, calcium and vitamin A for children and women. The high prevalence of anaemia among women and children is associated with the low bioavailability of iron in grains (EPHI, 2013), as is synergy with other micronutrient deficiencies (Gebru *et al.*, 2018). About 44 percent of children under five, 30 percent of adolescents, 22 percent of pregnant women and 17 percent of women of reproductive age are estimated to suffer from anaemia. Only 4 percent of children have minimally acceptable diets, a very low figure compared to other sub-Saharan African countries. At the same time, obesity and an increasing number of people with diabetes are becoming public health issues (Gebru *et al.*, 2018). Although the figures refer to national averages – meaning the situation is better in some communities and more serious in others – an overall lack of dietary diversity and low intake of pulses, legumes and animal-sourced food mean that the daily requirements of protein and amino acids are not being met (McKevith, 2004).

A balanced diet and adequate intake of nutritious food is especially important for children, pregnant and lactating women and the elderly. School feeding programmes aim to ensure at least one nutritious meal each day for school-age children; this also has positive effects on their achievements in school (Belachew *et al.*, 2011). Several national food aid initiatives are supported by local and international organizations, such as the World Food Programme (WFP) and other organizations, and these are discussed in Chapter 6.

Despite efforts to improve agriculture, the heavy reliance on cereal crops hinders efforts to promote improved diets in Ethiopia. Nevertheless, there are signs of a significant reduction in the prevalence of stunting among children below five years of age. In 1990, the prevalence rate was about 65 percent, compared to 40 percent in 2014 (EC, 2020), occurring in parallel with a rapid population growth (see Table 1). A reduction of this magnitude cannot only be attributed to changing diets and an increasing food supply, including imported food. It is, for instance, important that considerable improvements have been made in the supply of clean drinking water. In 2002, only 33 percent of the total population had access to improved drinking water, while in 2015, this figure was 57 percent. At the same time, sanitation coverage increased from 10 percent in 2001 to 28 percent in 2015 (FAO, 2016).

3.4 ADEQUATE FOOD SUPPLY AT THE NATIONAL LEVEL BUT IMBALANCES AMONG GROUPS

In terms of calories, the average food supply in Ethiopia, including imports, is estimated at 3 000 kcal cap^{-1} day^{-1} (Baye *et al.*, 2019), implying a high average level of food availability nationally. However, production, supply, access and diets vary significantly between socio-economic groups (Malmquist, 2018). High market prices for nutritious crops, compared to cheaper food items with high fat and sugar content, would stimulate farmers to diversify production, improve diets and reduce malnutrition (Bachewe *et al.*, 2017).

On the other hand, price incentives for farmers often have implications for consumers. Some years ago, the price of teff increased as a result of export opportunities. Teff is especially favoured by urban dwellers in Ethiopia and, increasingly, by the Ethiopian and Eritrean diaspora. Better marketing opportunities and an increase in prices naturally stimulated production. It also resulted in an increased price in the domestic market. Interestingly, the price of white teff tends to be higher than red teff, despite red teff being richer from a nutrition point of view, with a higher iron content. To reduce the negative effects for consumers in Ethiopia, the government imposed an export ban on teff and many other crops during 2006–2016.

4. Nutritional water productivity: data, calculations, and validity

Policies on food security have generally favoured an approach that maximizes caloric production (Pinstrup-Andersen, 2018). When too little food is produced in relation to basic needs, efforts to reduce hunger is naturally a key goal. Throughout history, a strong concern has been related the fear of hunger and starvation, reflected in the thinking of Thomas R. Malthus. During the latter part of the 20th century, the ratio between population number and level of food production and supply gradually changed. For several decades, the global food production has increased significantly and much more rapidly than population growth. As already mentioned, hunger is still widespread, e.g. in large parts of Africa, and in recent years, prevalence of hunger has again started to increase. However, the prevalence of other kinds of malnutrition, related to diets and food habits, is much higher (Lundqvist and Unver 2018). After decades of rapid increases in food production and supply, it is now recognized that strategies are needed to address a massive nutrition problem in the context of significant water challenges. The increased production, supply and intake of micronutrients, e.g. minerals and vitamins, are of critical importance in reducing widespread and serious malnutrition (Damereau *et al.*, 2019; Pinstrup-Andersen, 2018; Willet *et al.*, 2018; Nelson *et al.*, 2018).

4.1 EQUATIONS TO ESTIMATE NUTRITIONAL WATER PRODUCTIVITY IN FOOD PRODUCTION

The calculation of NWP is based on a set of equations developed by Renault and Wallender (2000).

The basic equation for water productivity (WP) is:

$$WP = \frac{Y_a}{ET_a} \quad [\text{kg m}^{-3}] \quad [1]$$

Where Y_a is the average actual crop-specific yield and ET_a is the average actual evapotranspiration per cultivation season. Ideally, Y_a should be the average yield for a specified location for which ET_a is estimated, as both Y_a and ET_a are location specific. 'Average' in this context of Ethiopia as example, refers to average yield over three years: 2015–2018. For comparable values of WP between seasons, seasonal values of ET_a and Y_a are used.

The NWP includes the macro- and micronutrient contents (e.g. energy, protein, iron, zinc, etc.) of the specified crop in relation to water input (evapotranspiration: equation [2]).

$$NWP = \frac{Y_a * NC_{crop}}{ET_a} \quad [\text{nutrition content per m}^3] \quad [2]$$

Where NC_{crop} is the nutrient content for the specific crop measured in grams, milligrams, micrograms and kcal per kg crop and ETa is the average actual evapotranspiration per cultivation season and crop (as in eq. [1] (see Table 4, Appendix A).

The water input is based on values of evapotranspiration and calculated according to equation [2]. The ratio of transpiration to evaporation can be modified through land/soil management and conservation, and by timing and coordination of operations during the cultivation season. Land management that reduces or slows down the rate of runoff and facilitates the infiltration of water, together with mulching and other measures that improve water holding capacity in the root zone, are important measures in such a strategy (Rockström and Barron, 2007). With erratic rainfall, the timing of operations remains a serious challenge for farmers.

NWP calculations based on reviewed values on WP (=Y Et_a^{-1}) (see Table 4, Appendix A) were calculated using equation [3].

$$NWP = WP * NC \quad [\text{Nutrition density m-3}] \quad [3]$$

Due to differences in climate, abiotic and biotic stress factors, actual evapotranspiration varies. These differences are taken into account in terms of intervals of ET_a and WP (equations [2] and [3]).

Various sets of data about crops cultivated in Ethiopia, their nutrition contents and water conditions, as summarized in Tables 3-6 in Appendix A, are used in the analyses.

4.2 SOURCES OF DATA

The availability and reliability of data are major challenges to measuring the nutritional water productivity of crops in Ethiopia. Secondary data sources on the yields of major crops under both irrigated and rainfed production systems were collected from different sources,[9] taking into account crop variety, cropping system, soil type and growing conditions. In addition, dietary diversity data for the major crops in Ethiopia were collected from the International Food Policy Research Institute (IFPRI) and the Ethiopia Central Statistical Agency (CSA).

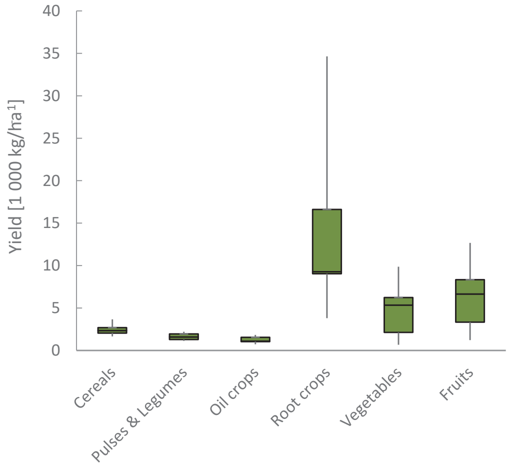
Below are some observations around the data sources used in the calculation of NWP:

- Potential evapotranspiration differs between geographical locations (FAO, 2012) depending on, e.g. differences in climate and agroecological zones and crop species. Actual evapotranspiration also depends on biotic and abiotic stresses, such as soil water availability, nutrient access or impact from pests or diseases. References from Ethiopia on actual evapotranspiration and water productivity are limited and refer primarily to carbohydrate-rich crops, such as cereals and potato. Further, available studies mostly refer to trials of different methods of irrigation. Due to limitations in the availability of data, intervals of evapotranspiration have been identified. In addition to available data from Ethiopia, data from other countries with relevant intervals of evapotranspiration were used to calculate water productivity for crops cultivated in Ethiopia (see Table 3, Appendix A).
- The values of water productivity used in the calculations are based on a review of several studies that are synthetized in Table 4 in Appendix A. Other data sources were also used for the calculation of water productivity, including the Global Yield Gap Atlas, FAO Food Balance Sheets, etc.
- Values for the nutrition density of crops (Table 4, Appendix A), were collected from EPHI (2013). Missing data on nutrition density were complemented with values from Baye (2014); Lukmanju and Hertzmark (2008); FAO and the Government of Kenya (2018); the West African Food Composition Table (Stadlmayr, 2012) and the USDA Nutrient Database (undated) (www.nal.usda.gov/fnic/foodcomp). The nutrition content of individual crops used in the calculations refers to non-processed crops. This includes nutrition content from whole cereal grains and average values for dried and fresh pulses and legumes, dried nuts and oil crops, raw and fresh vegetables and fruits.
- The CSA does not disaggregate data between varieties of crop species. Because different varieties of the same crop species may vary in terms of nutrient content and crop water demand, and the food composition tables contain nutrient content values for different varieties, the average nutrient values have been used for teff, barley, wheat, maize, sorghum, finger millet, faba bean, field pea, haricot beans, chickpea, onion, potatoes, guava, and lemon.
- Yield data come from CSA and the average yields from 2015 to 2018 were used in the calculations. Due to considerable national variation in evapotranspiration and yields, NWP values have been calculated as intervals with the highest and lowest evapotranspiration and the maximum and minimum values of WP as identified in the review of WP in Ethiopia. This allowed us to make a reasonable estimate of the likely range of NWP values in Ethiopia.

[9] Such as the Global Yield Gap Atlas, FAO SOLAW, FAO WaPOR, FAO Geonetwork, etc.

FIGURE 1

Average yield (seasons 2015–2018). The categories include data for the fresh weight of major crops produced in Ethiopia



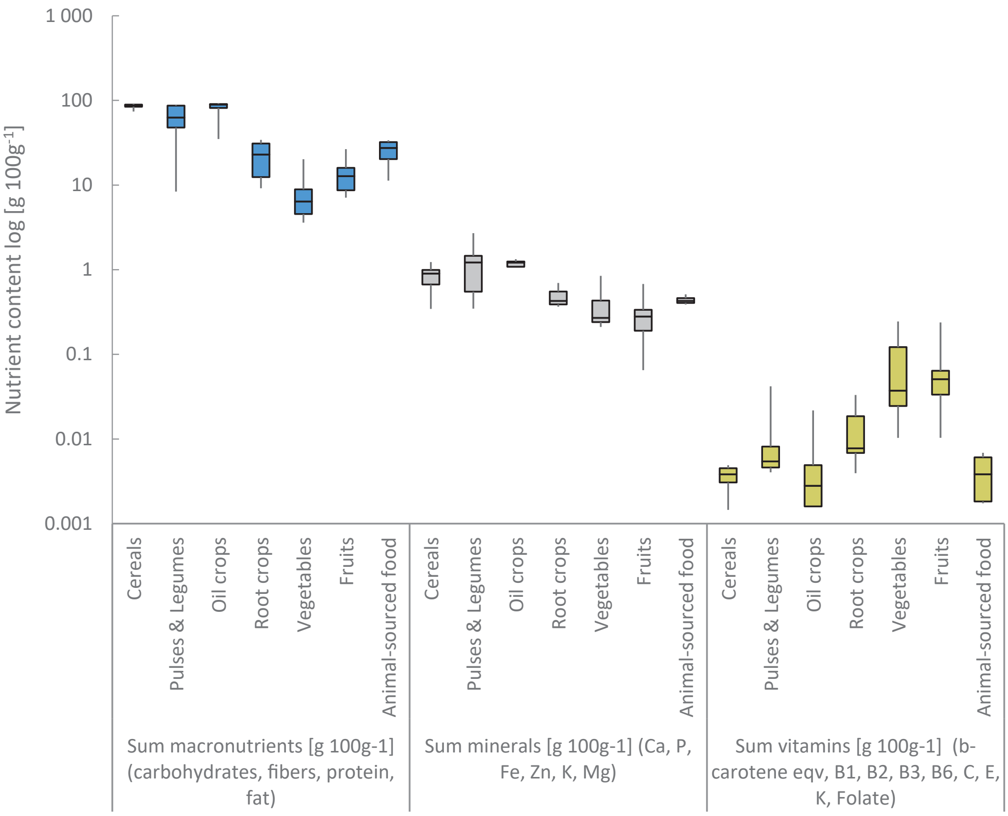
Source: Ethiopia Central Statistical Agency. Green bars represent 50 percent of the crops per category. Root crops includes the crops beetroot, carrot, onion, potatoes, garlic, yam, taro and sweet potato.

4.3 DESCRIPTION OF THE CALCULATIONS

Figure 1 illustrates the wide variation in yields within and between the categories of crops produced in Ethiopia. As expected, the highest yields are reported for root crops, e.g. sweet potato (34.6 tonnes ha^{-1}), taro (25.3 tonnes ha^{-1}), potatoes (13.7 tonnes ha^{-1}) and yam (9.2 tonnes h^{a-1}). These crops have a high water content but also a relatively high density of macro nutrients (Table 5 and Figure 2). The yields for fruits and vegetables can also be high, e.g. papaya (14.8 tonnes ha^{-1}) and garlic (9.1 tonnes ha^{-1}) and these crops are rich in vitamins and minerals (see Figure 2). Both root crops and fruits and vegetables show a significant variation in yield within their respective category. By comparison, both the level and the variation in yield of cereals are comparatively small.

FIGURE 2

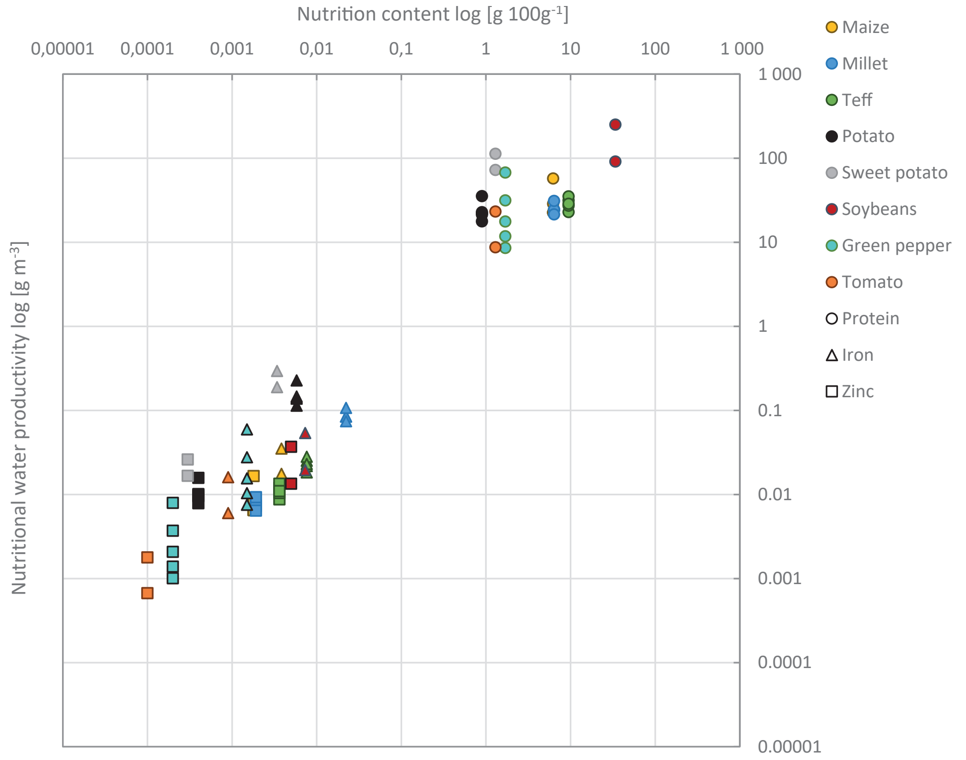
Average macro- and micronutrient content for main crop categories and animal-sourced food. The categories include data for major crops and animal-sourced food produced in Ethiopia. Detailed nutrition content for the crops included in the different categories are shown in Table 5 in Appendix A. Note log scale on the y-axis



The nutritional water productivity and nutrient density of a few selected crops are illustrated in a log-log diagram (see Figure 3). As shown in Figures 1 and 2, there is a wide range in terms of nutrient density and nutritional water productivity between and among crops. For instance, soybeans have a high density of protein and also a high nutritional water productivity for protein but a lower nutritional water density with regard to zinc.

FIGURE 3

Nutritional composition and NWP for rainfed crops: maize, millet, sorghum, teff, potato, sweet potato, soybeans and groundnut, calculated using data from Ethiopia. Intervals of nutritional water productivity for some principal crops – calculated with global average values of evapotranspiration – are presented in Tables 2 and 3 in Appendix A



4.4 VALIDITY

It is important to combine NWP calculations with an analysis of the risks, opportunities and returns to farmers arising from a transformation of their production system. For example, some crops with a high nutrient density are sensitive to moisture stress. The demand for crops that are important for improved nutrition – and their prices – can be volatile. Furthermore, farmers' decisions to invest in the cultivation of particular crops are influenced by their experience and capacity, e.g. the availability of labour.

It is important to stabilize yields at realistically attainable levels; this is true for crops that provide basic food security and particularly for high-value crops and crops with high nutrient density. Given small holdings and water challenges, farmers are not likely to abandon the cultivation of less risky crops in favour of riskier, albeit more nutritious and economically promising crops. The outlying cases, i.e., cases in the upper parts of the bars in Figure 1, indicate that yields differ substantially within crop categories. The potential to increase yield levels above average on the other hand differs between crops. Nevertheless, if successful, efforts to increase and stabilize yields are likely to have multiple benefits:

- *Farmers* will benefit from continuing to cultivate crops for basic food security while using some of their land and water resources to grow crops with a higher nutritional and economic value.
- *Society* will benefit from progress on nutrition goals, reduced dependence on food imports, stronger market links between rural areas and between rural and urban areas, and increased supply of products to the food processing industry (including meat and dairy) (e.g. Wakeyo, *et al.,* 2016).
- *The environment* will benefit from increased resource use efficiency and the reduction of threats of an expansion of agriculture into other ecosystems.

Under the current circumstances, smallholder farmers tend not to give much attention to nutrition in determining how to use the limited land and water resources available to them. As noted by Pinstrup-Andersen (2018) with reference to farmer decisions, "whether we like it or not, the 'value' in food value chains is economic value, not nutritional value." Given the prevailing low and fluctuating yields, with no surplus, market opportunities and food procurement programmes will not be strong drivers of a transformation of agriculture and food systems. Considering Ethiopia's erratic rainfall, it is not surprising that yield varies greatly from season to season, especially in rainfed systems. There is also a risk that the nutrient content and economic value of crops will be affected by moisture stress, making it more difficult to sell the produce at a reasonable price (Bryan *et al.*, 2019).

4.5 NWP FOR PLANT-BASED VERSUS ANIMAL-SOURCED FOODS

There is a widespread view that significantly more water is required to produce animal-sourced food than food sourced from plants. This view reflects calculations that include the water needed to produce feed for cattle and other animals without reference to the different contexts in which crops and feed are produced. Calculating the amount of water required to produce the nutrients in milk and meat in Ethiopia suggest quite low NWP values, with estimates in the interval 0.05–6.9 g m^{-3} for macronutrients, 0.0004–77.0 mg m^{-3} for minerals and 0.0001–1.7 mg m^{-3} for vitamins. The NWP for plant-based food is generally much higher. For example, the NWP for potassium in sweet potatoes can be up to 21 739 mg m^{-3}, and the calcium content in soybean also has a high NWP, up to 1 676 mg m^{-3}.

Efforts to compare differences in the water requirements to produce animal- and plant-sourced food should pay due attention to the context in which production occurs. Animal rearing in Ethiopia and in other parts of Africa by pastoralists and agro-pastoralists primarily occurs on land that is suitable for grazing but not for crop production. In these areas, the water and land needed to produce feed does not compete with water and land that can be used for the production of food crops.

The livelihoods of pastoralists and agro-pastoralists are very much affected by erratic rainfall and the growing competition for land and water (Tsegaye *et al.*, 2016, ILCA, 1993). Animal-sourced foods contain high-quality proteins (Willet *et al.*, 2016), as well as vitamin B12 and heme iron, which are not available in non-animal foods. For the large majority of people in Ethiopia and other African countries, the intake of animal-sourced food is low due to high prices, among other things, which makes it inaccessible to low income households. Farming systems that include a combination of plant-based and animal-sourced food may be valuable in a double sense: they provide nutrition in communities where the intake of high quality animal-sourced food is very low and they enable a diversified use of land and water resources.

Research is beginning to take note of the fact that the production of various food items, including livestock feed, takes place in different water and land use contexts (Damerau *et al*., 2019; Mottet *et al*., 2017; Jalava, 2019). In analysing water requirements for animal-sourced food, it is critical to recognize differences in livestock feeding practices, e.g. between feedlot management systems and the more extensive management systems that are typical in agro-pastoral systems.

4.6 DEVELOPMENT OF THE NUTRITIONAL WATER PRODUCTIVITY (NWP) FRAMEWORK

NWP has been calculated in different countries and using different designs. An analysis by Renault and Wallender (2000) of nutritional productivity in terms of the energy, protein, calcium, fat, Vitamin A, iron output per unit of water input in California showed that vegetal products are much more productive in relation to water requirements than are animal-sourced food products. However, the authors did not consider animal-sourced foods from cattle grazing in areas where there are no realistic alternative options to use land and water, as discussed in Section 4.5. NWP calculations have been done for the production of food as well as for the food in the diets of three different socio-economic groups in Ethiopia, Tanzania and Burkina Faso (Malmquist, 2018). Looking at Spain, Blas *et al.* (2019) distinguished between water inputs for evapotranspiration and included estimates on the degree of water quality degradation in their calculations. NWP has also been calculated for specific crops e.g. amaranth, Swiss chard and spider flower in South Africa (Nyathi *et al*., 2018); groundnut, dry bean, bambara groundnut and cowpea in South Africa.

In developing an NWP framework, a few issues stand out:

- It is critical to pay attention to variations in nutritional value along the food value chain. Many high-value crops with a high density of important nutrients are vulnerable and require proper post-harvest arrangements to ensure that their economic and nutritional values benefit farmers as well as society.
- Animal-sourced and plant-sourced foods are, at least partly, produced in different contexts (as seen in Section 4.6). Mainstream calculations ignore that livestock feed may be produced in areas that are not suitable for crops intended for humans to prepare food and eat.
- Quality and access to reliable data are basic challenges. Reliable data on water requirements for various types of food and the nutrient contents of crops and diets are necessary to guide national policies, for example, as a basis for incentives to increase the production of crops that can reduce high levels of malnutrition.

Recent developments in land-cover maps and evapotranspiration maps available in WaPOR[10] are promising for improving the quality of estimates for direct use in policy. High-resolution maps down to 30 metres have been developed in eight areas distributed over Kenya, Lebanon, Ethiopia, Mali, Egypt, Mozambique and Sudan.

[10] WaPOR is an FAO programme that analyses prospects of improvements in water productivity, at four different scales of aggregation/resolution: continental, country, river basin and sub-basin. See www.fao.org/in-action/remote-sensing-for-water-productivity/wlpa-introduction/geographical-coverage/fr/_

Resolution down to 100 metres is available on a national scale for 21 countries. This resolution is still not high enough to account for differences between crops on fields smaller than a hectare.The implementing agency (CAREWWF) in the Uluguru Mountains conducted a cost-benefit analysis showing that opportunity costs are key in the design of a PES scheme. This PES-type case study shows how estimating opportunity costs is a key factor in the design of PES schemes to ensure farmer participation. Long-term involvement of farmers is also necessary to meet the timescale requirements to restore the functionality of ecosystem processes (excerpts from FAO, 2011).

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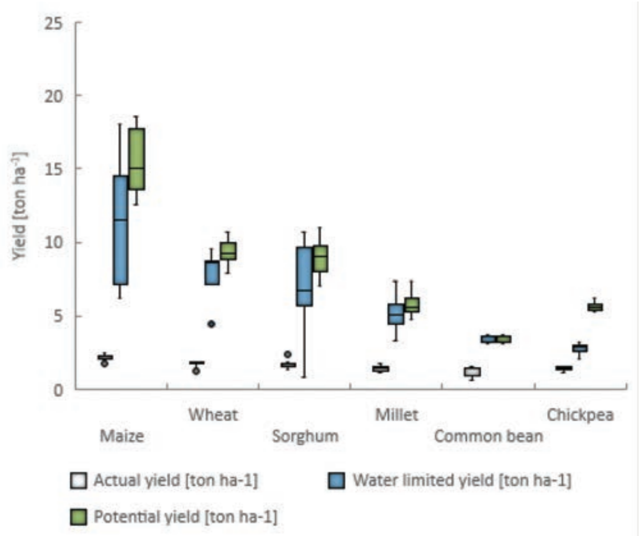
5. The yield gap and the links to diversification and nutrition outcome

5.1 WATER AND THE YIELD GAP

In the literature, distinctions are made between the estimation of yield gaps in irrigated and rainfed systems. Potential yields in irrigated systems are estimated without production limitations in terms of water input, plant nutrient or biotic factors, while the benchmark for potentially achievable yields in rainfed systems is determined by the limitation of water in the cropping system for actual yield, water and plant nutrient limitations; impacts from pests and weeds are also accounted for (www.yieldgap.org/web/guest/gyga-publications, www.yieldgap.org/documents/10180/35397/2013 percent20FCR percent20vanIttersumetal percent20Yield percent20Gap percent20Analysis percent20Review.pdf).

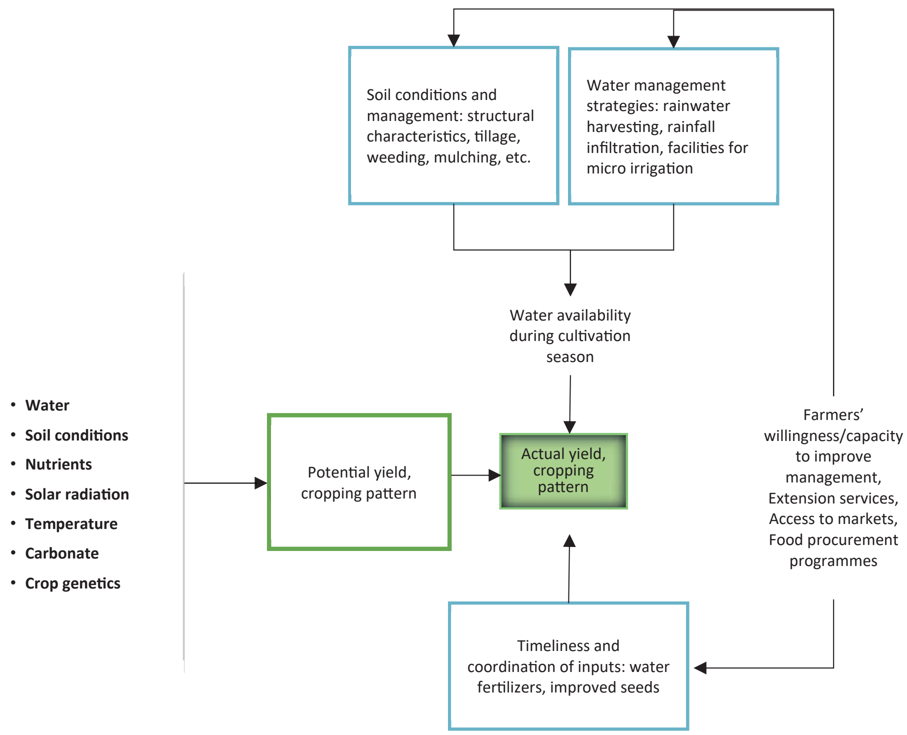
FIGURE 4
Average actual yield, water-limited yield and potential yields for some of the major crops in Ethiopia. Adapted from data from the Global Yield Gap Atlas



For valid estimates,[11] accurate climate data and knowledge of the crop water requirements, based on climate data on solar radiation, temperatures, precipitation, air humidity and wind speed, are assumed. The benchmark for potentially achievable yields in rainfed systems is determined by the limitation of water in the cropping system (see Figure 4).

To increase the actual yield to its potential level, a number of management tasks need attention. With or without support and guidance from outside, smallholder farmers may improve the coordination and timeliness in their use of water and other inputs. For a modification of the cropping pattern, additional management tasks may be required, e.g. the development of links to markets, procurement programmes and similar (see Figure 5).

FIGURE 5
A schematic illustration of factors determining potential and actual yields



[11] Potential yield (Y_p) is determined by sun radiation, temperature, carbon dioxide and crop species and genetic varieties (www.yieldgap.org/web/guest/methods-overview).

5.2 POOR COORDINATION OF WATER AND OTHER INPUTS

As described in Chapter 3, the actual use of fertilizers and improved seeds has increased. Nevertheless, information on the use of fertilizers is limited. For example, the Ethiopia Central Statistical Agency does not include information on the per hectare application rates of fertilizers. Overall, the use of improved seeds has increased as well, from 44 918.6 hectares in 2006 to 122 508.4 hectares in 2015 during the main cropping season (Dawit *et al.*, 2017), but this is only about 10 percent of the area sown to permanent crops (see Table 1).

Only a very small part of Ethiopia's cultivated land is provided with irrigation (see Figure 6). Maize, for example, is the most widely cultivated crop in Ethiopia, yet only about one percent of the cultivated area is irrigated. Historically and currently, a small part of the area cultivated with sorghum and teff have been irrigated. The irrigation of fruits and vegetables, e.g. tomatoes and lemon, is more common (Erkossa, 2018), but official data suggest that less than half of the area cultivated to these crops is irrigated (see Figure 6). For other valuable crops, for example, papaya and orange, around 20 percent of the area is irrigated. But reliable data on actual use and variation are limited. For instance, data and information on the difference between area provided with irrigation facilities and the area that actually receives water, make it difficult to do these kinds of analyses.

Even if crop yields have increased in Ethiopia, they are still low by international standards. With reference to the information compiled in Figure 4, it is interesting to interpret the yield gap in terms of a combination of poor water management and other circumstances. The level of coordination and timing of water and other inputs in agriculture are obviously important for yield level.

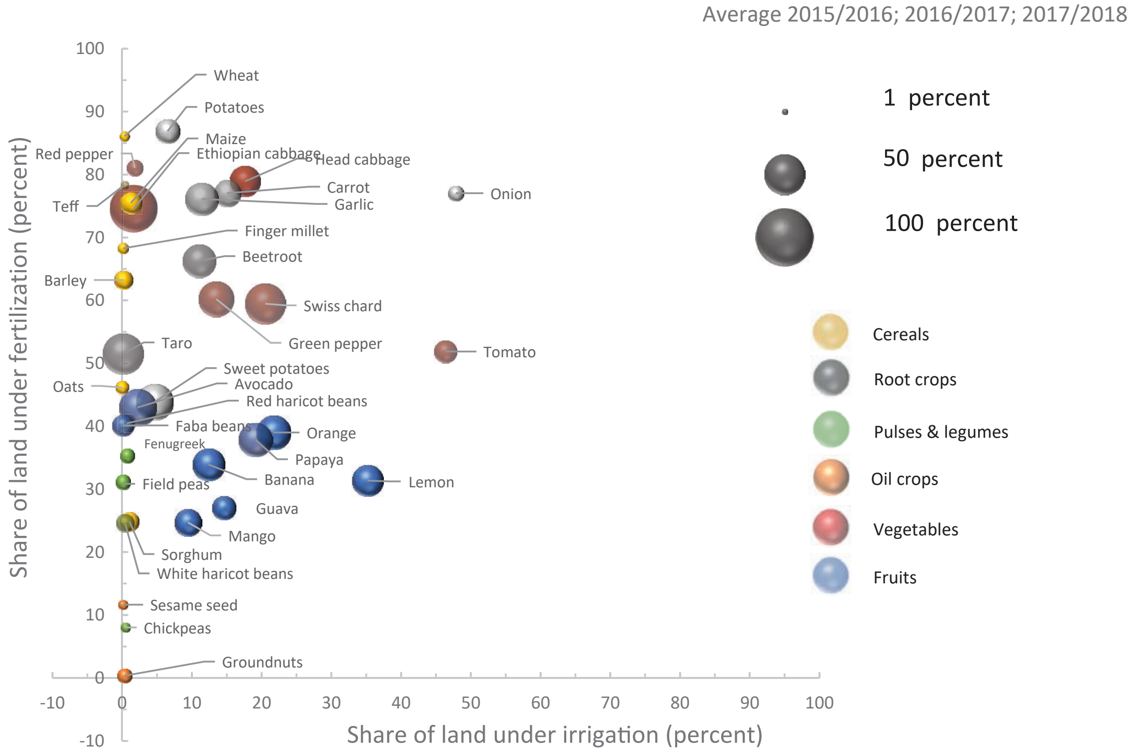
Figure 6 shows that the use of fertilizers is much more common as compared to water provision through irrigation.[12] Since soil and water conservation are also important in efforts to reduce the negative effects of dry spells, data on these efforts are displayed in terms of the size of the bubbles in Figure 6. It was not possible to find reliable information on rainwater harvesting, which is another component in water management and sometimes twinned in S&WC programmes.

Two important features are illustrated in Figure 6. There seems to be no spatial covariation between irrigation facilities and soil and water conservation. With an increasing share of land under irrigation, it rather appears that the likelihood for soil and water conservation is reduced. With access to 'easy water,' farmers may be less motivated to invest in rainwater harvesting infrastructure (Wakeyo and Gardebroek, 2017) and water conservation. Since the major drought and famine of 1973/74, however, the Government of Ethiopia and international donor programmes have invested heavily in soil and water conservation projects.

[12] The Central Ethiopian Statistical Agency does not provide details on irrigation, i.e., if the data refer to an area that s equipped with irrigation facilities, what kind of irrigation is used and other details of how irrigation is practiced.

FIGURE 6

Average share of land under irrigation in relation to share of land under fertilization for the seasons 2015/2016 to 2017/2018 at the national level. The bubble size represents share of land where soil and water conservation have been used. Calculated from data from the Ethiopia Central Statistical Agency



As can also be seen in Figure 6, fertilizers are relatively more widespread than irrigation in Ethiopia. This is in line with the results presented in the comprehensive study by Sheahan and Barrett mentioned above (2017). Based on an analysis of data from six countries in Africa, including Ethiopia, the authors found that the use of inorganic fertilizers is much more widespread, both at household and plot levels, than irrigation and also more common than the use of improved seeds. Coordinated use of inputs is quite poor, both at household and plot levels, as seen in Ethiopia and Niger (see Figure 7).

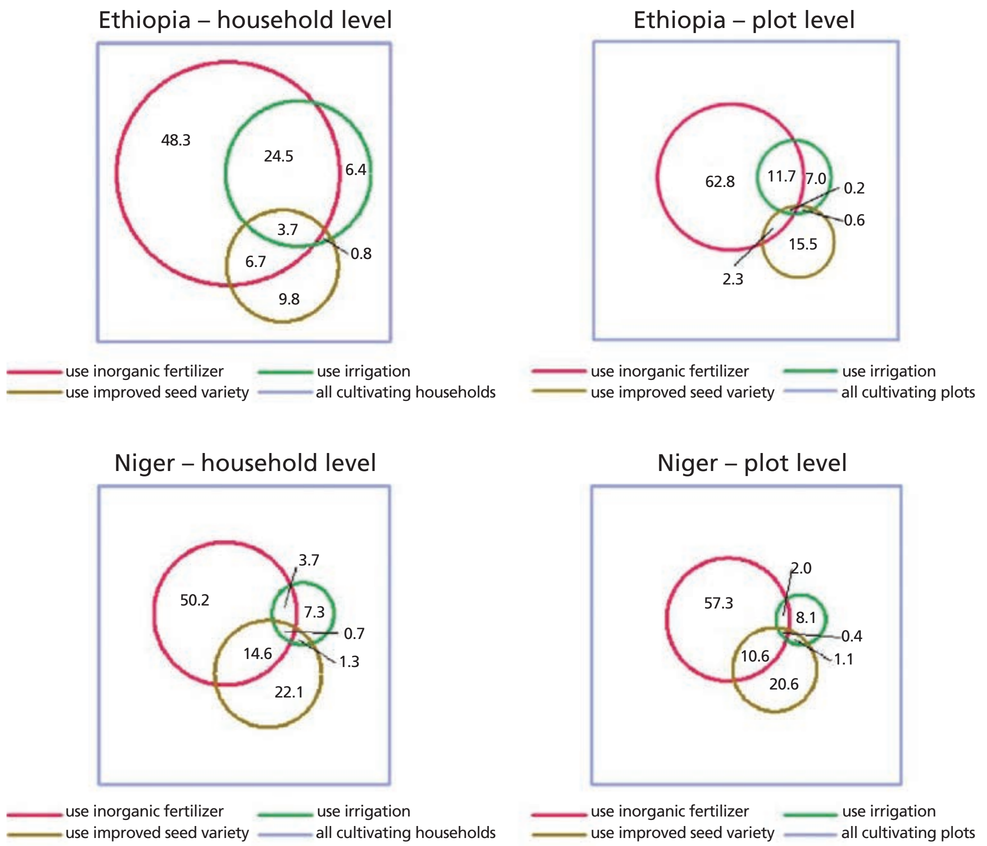
Two issues arise. One is that the use of inputs that are likely to increase yields, improve income and provide incentives to cultivate high-value crops, including crops that are important for improving nutrition, has increased in Ethiopia, although from very low levels. In other countries, the use of 'modern inputs', e.g. improved varieties of seeds, irrigation and mineral fertilizers, is higher than what is commonly assumed based on statistical information (Sheahan and Barrett, 2017). A related issue refers to the poor coordination and combination of inputs. Surprisingly, this also appears to be the case for cash crops (Sheahan and Barrett, 2017).

Practical circumstances may explain the relatively higher use of mineral fertilizers and improved seed varieties compared to irrigation. It is relatively easy for farmers to get access to different kinds of fertilizers and improved seeds in shops and other outlets and to distribute them among different plots. Access and the use of water in suitable volumes through various types of irrigation infrastructure, require more effort. Similarly, the need for irrigation varies between seasons depending on variation in rainfall. Planning and care of irrigation facilities, e.g. removing silt and maintenance of technical equipment, takes time and requires skills. These kinds of efforts are not required for the purchase and application of mineral fertilizers and improved seeds. Apart from arrangements within single holdings, irrigation facilities generally require joint effort within the farming community or between farmers and some kind of organization outside the single farm. As a contrast, farmers who have acquired fertilizers, improved seeds and similar inputs, can decide how to use them by themselves.

The lack of coordination of inputs that are likely to increase yields in Ethiopia, as illustrated in Figures 6 and 7, has been documented in other publications (e.g. Derib *et al.*, 2011; Van Halsema *et al.*, 2011; Eguavoen *et al.*, 2012). Similar findings in many studies illustrate the need for information and guidance, e.g. through extension services, on how farmers can effectively increase their yields. Simply by coordinating the inputs that already are available to them, farmers could probably significantly boost water productivity, yields and return on labour. Such modifications in management are important for paving the way to diversifying cropping patterns, for instance, by increasing the cultivation of high-value crops, including crops that are important for improving nutrition.

FIGURE 7

Illustration of the different levels use and the poor coordination of inorganic fertilizers (red circle), irrigation (green circle) and improved seeds at household and plot levels in Ethiopia and Niger. From Sheahan and Barrett (2017)



5.3 MICRO-IRRIGATION IN RAINFED AGRICULTURE

Traditional irrigation has existed in Ethiopia since antiquity. Starting in the 1950s, the interest in modern irrigation systems increased with a commitment by the government and commercial interests to stimulate the production of export crops. Currently, Ethiopian farmers employ two categories of irrigation systems: one category comprises schemes that are planned and implemented by the government, sometimes with support from donors; and the other includes systems that are primarily initiated, constructed and managed by farmers. In both cases, a variety of technologies and arrangements are developed and used to manage water resources.

Based on a classification by the Ministry of Water Resources, irrigation projects in the first category are identified as large-scale if the size of the command area is greater than 3 000 hectares; medium-scale if the command area is in the range of 200 to 3 000 hectares; and small-scale if the command area is smaller than 200 hectares (MoWR, 2015; Werfring, 2004; Awulachew *et al.,* 2005). Donor support can be substantial, for example, in the Agricultural Growth Programme project, where about 40 percent of the budget was financed by donors.

The other category of irrigation development in Ethiopia comprises household irrigation. Under this category, individual farmer households and groups of farmers invest in technologies and arrangements for harvesting water for multiple uses. This may involve various sources of water, e.g. streams/river diversions, harvesting of local rainfall and flash floods, shallow groundwater for storage in ponds, shallow wells, and similar. With a combination of water and soil conservation, the soil will be able to store part of the rainfall, where otherwise, it would have increased the run-off of local rainfall. Sharing small dams or ponds among farmers is common. Aside from using water to reduce risk and to counter the negative effects of dry spells, these arrangements make it possible for farmers to increase their productivity. Often, the farmers use water to cultivate high-value and nutritious crops in addition to staple crops like maize, particularly green maize, which can be sold at a reasonably good price. The demand for green maize is very high, especially in cities like Addis Ababa, where women and girls roast and sell the vegetable by the roadside. This is an example of a small-scale informal business that is important for local communities but for which reliable data are missing.

The collection and use of rainwater is important, not only in agriculture and for direct social gains. For instance, to ensure a better survival rate of seedlings in connection with seedlings of fruit trees and the currently ongoing ambitious tree planting programme in Ethiopia, arrangements are made to provide small amounts of water to the site where seedlings are planted.

Based on compilation of data from 2010, the average size of household irrigation plots is small, or about 0.25 hectares, mainly due to limitations posed by water sources and capacity for storage. Although most schemes are initiated and managed by households, some schemes of this size are constructed by the government but managed by farmers.

Both categories of irrigation schemes are in a dynamic phase of development. As in many developing countries, the visibility of schemes in the first category is comparatively high. However, it seems clear that there is a substantial expansion in the use of irrigation technologies and activities at the individual household and community levels. The magnitude of this development is still unknown. For instance, ponds constructed by individual farmers or in partnership with neighbors are not included in official records on irrigation (Wakeyo and Gardebroek, 2017).

The Ethiopian government and the Ministry of Water, Irrigation and Energy is working with the Ethiopian Agricultural Transformation Agency (ATA) and other partners to develop a range of irrigation opportunities for farmers.

Household irrigation schemes in Ethiopia have similarities to what is commonly referred to as farmer-led, micro-irrigation in SSA and Asia. Several characteristics of farmer-led micro-irrigation have been identified (Lefore *et al.*, 2018):

- self-provisioned access to water;
- range of technologies used, including water harvesting arrangements and hand-dug wells;
- individual, household or group scale, e.g. ponds shared by a few households;
- multiple sources of water, e.g. diversion from small streams, hand-dug wells and lifting of water from shallow sources;
- lacking in formal governance of water sources;
- supplemental and dry season irrigation;
- multiple uses of water (livestock, domestic).

Household irrigation schemes have multiple and linked benefits in terms of increased income, possibilities to diversify cropping patterns, food security and nutrition (Lefore *et al.*, 2019). Because they are initiated and managed by farmers, such schemes foster a feeling of ownership and control of the means of production, which is important for entrepreneurial skills and rural development. Using the harvested water according to household preferences, farmers and their family members are starting to enjoy the nutritional and income benefits in some parts of Ethiopia. As a result, young girls prefer young men who own ponds as husbands and the saying 'no pond no wife' has emerged as a proverb in East Ethiopia (Gezahegn *et al.*, 2006).

Evidence shows that it is often the younger, better-off male members of the community who benefit from farmer-led irrigation. There is a need for institutional arrangements to guide irrigation expansion to avoid or minimize undesirable social and environmental consequences in different parts of a basin. For example, there is a risk that water availability in downstream segments will be reduced as a result of an expansion of irrigation and an intensified use of water in upstream parts of a basin (Lefore *et al.*, 2019). A successful development of irrigation schemes in upstream segments of basins imply that the flow and availability of water to downstream segments are reduced. Conflicting interests between upstream and downstream people, may thus require institutional arrangements with the involvement of a third party.

Support is also required to access irrigation technologies and financial services that are limited by a lack of properly functioning technology supply chains (Lefore *et al.*, 2019). In Ethiopia, a shortage of the basic materials needed for constructing ponds, i.e. plastic geomembranes, and other factors have constrained the extensive use of water harvesting technologies in the eastern parts of the country (Wakeyo and Gardebroek, 2015).

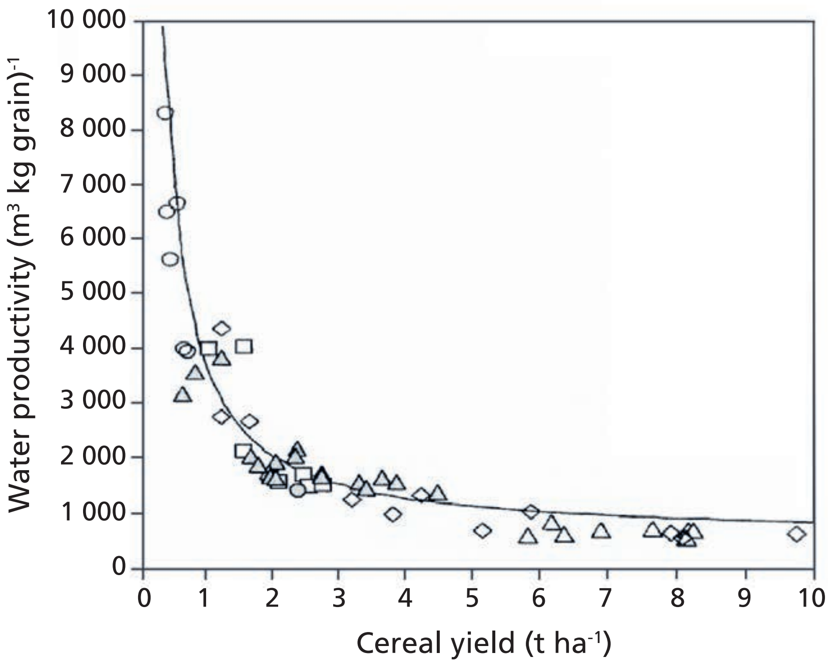
The potential to expand irrigation at different levels may be revisited, given the emergence of new technologies, e.g. the use of solar power (Schmitter *et al.*, 2018) and other non-fossil sources of energy.

5.4 HIGH MARGINAL PRODUCTIVITY POTENTIAL FROM SUPPLEMENTARY WATER

Arrangements that make it possible for farmers to add small amounts of supplementary water, e.g. through irrigation schemes such as discussed above, have proven to have significant benefits. The graph presented in Figure 8 illustrates that water added to rainfed systems where low yields dominate (i.e. < 3 tonnes) is likely to have a comparatively high return in terms of increasing and stabilizing yields and enabling farmers to expand their cultivation, as discussed in Chapter 4.5. The marginal productivity gained by adding limited amounts of water at low yield levels is much higher than that gained from adding more water in systems where yields are already relatively high.

The previous discussion makes it clear that the common dichotomy between rainfed and irrigated systems is too simplistic. It is important to recognize that there is a wide array of water needs in farming systems, ranging from systems that are only or primarily rainfed to those where irrigation is the only possible source of water. Finally, it is relevant to mention that micro-irrigation arrangements used to supplement deficiencies and variation in rainfall are much less a threat to the water supply in downstream segments of basins than are large-scale irrigation schemes, which are associated with a heavy withdrawal of water from rivers, aquifers and other sources of water. To realize the potential of micro-irrigation, it needs to be combined with soil and landscape interventions (e.g. to control erosion and for environmental management) and coordinated with inputs other than water.

FIGURE 8
Illustration of the non-linear relation between yield and water input/productivity



Source: Rockström and Barron (2007).

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6. Incentives for smallholder farmers production of nutrient-dense crops

As discussed, low agricultural productivity is a significant barrier to smallholder participation in markets. Indeed, increasing farmers' yields can be seen as a key to improved livelihoods and the production of nutrient-dense crops. At the same time, links to markets also need to be strengthened (Poole, 2017). Currently, most smallholder farmers, particularly in sub-Saharan Africa, are subsistence farmers with little marketable surplus, making them net buyers of food and dependent on food aid programmes and imports.

Like other economic actors, smallholder farmers respond rationally to price incentives and are likely to produce high-value and nutrient-dense crops if they have the incentive to do so. Urbanization and the increasing standard of living of urban populations, especially in secondary cities, offer positive market prospects for smallholder farmers (Yigrem *et al.*, 2008). In this regard, simply improving supply-side conditions, such as through farmer training programmes and extension services and access to input and credit, may not be an adequate strategy.

Nearly every country, both developed and developing, implement school feeding programmes (WFP, 2013a). The global investment in such programmes is about USD 75 billion a year, with more than 368 million children receiving meals every day (WFP, 2013a). India's Midday Meal Scheme is the largest school meals programme in the world, feeding 105 million children every day (World Bank, 2015. Empirical evidence (e.g. Yigrem *et al*., 2008) suggests that expediting farmer access to guaranteed, financially -rewarding markets through such programmes can encourage smallholder farmers to invest in high-value and nutrient-dense crops.

To facilitate the participation of local producers, particularly smallholders, WFP developed the home-grown school feeding initiative (HGSF), which provides locally-produced food to school feeding programmes. Through HGSF, WFP links school feeding programmes with local farmers, who provide millions of schoolchildren in 46 countries (including Ethiopia) with food that is safe, diverse, nutritious and, above all, local (www.wfp.org/home-grown-school-feeding). Connecting smallholder farmers to school feeding secures them a regular and reliable income (https://hgsf-global.org/en/what-is-hgsf-), leading to more investment in agriculture production and higher productivity. At the community level, HGSF initiatives promote nutrition education and better eating habits, and encourage the diversification of production, with a special emphasis on local crops (www.wfp.org/home-grown-school-feeding).

Another WFP programme that provides market opportunities to smallholder farmers is the Purchase for Progress (P4P) programme. The programme combines WFP's purchasing power with the technical expertise of partners to build the capacity of smallholder farmers to participate in food commodity markets. Through P4P, WFP intervenes on both the demand and supply sides: i) on the demand side by providing market opportunities for smallholder farmers (through farmers organizations) who would normally not have access to competitive and remunerative markets; and ii) on the supply side by providing technical support to help farmers improve the quality of their production to reach more competitive markets.[13] P4P eliminates many barriers to smallholder farmers market participation by transferring the technical knowledge and skills they need to increase the quality and quantity of their marketable surplus, while helping them to access the demand of the largest purchaser of food aid in the world (WFP/P4P, 2014). In partnership with HarvestPlus[14] and national governments, P4P has also promoted the production and distribution of micronutrient-rich crops (iron-rich beans, vitamin A maize and vitamin A sweet potato) in Rwanda, Uganda and Zambia. Here, farmers benefit from improved nutrition and increased incomes by selling their produce in school meal programmes (P4P, 2014).

While the above-mentioned programmes provide important market opportunities for smallholders, farmers still face challenges due to their low yields and poor quality produce, making it difficult to meet the standards of large buyers like WFP. In addition, high transportation and transaction costs due to poor rural infrastructure, combined with long distances between production areas and markets can effectively block access to markets. Other constraints include market information asymmetries between farmers and market actors, access to finance and technology, and climate and weather

[13] It is important to note that, due to quantity requirements, smallholder farmers participate in P4P programme through farmers' organizations, which serve as a connection point between P4P and the farmers.

[14] HarvestPlus is part of the CGIAR Research Program on Agriculture for Nutrition and Health (A4NH), based at the International Food Policy Research Institute (IFPRI). It helps to realize the potential of agricultural development to deliver gender-equitable health and nutritional benefits to the poor (www.harvestplus.org/about/our-mission).

variability. FAO can play a key role in providing technical and capacity-building support to farmers on water management, soil and agronomic practices, post-harvest handling techniques, promotion of micronutrient-rich crops through bio-fortification, etc. Institutional procurement programmes are just one of the options available to support the participation of smallholder farmers in markets. Policies that incentivize the establishment of small-scale agro-processing industries in production areas, could reduce the high transportation costs associated with the long distances between production and markets. In addition, there is a need to identify pro-smallholder models in public and private procurement systems that can be adopted, adapted and scaled-up by national governments.

There is an emerging market for high-value and nutrient-dense vegetables and fruits provided by supermarket supply chains. According to Blandon (2006), there are several ways for farmers to supply their produce to supermarkets:

- *direct supply* to supermarkets or to their distribution centres;
- *indirect supply* to specialized wholesalers that supply produce to supermarkets;
- *indirect supply* though farmers' organizations that can sell to specialized wholesalers or directly to the supermarket.

Overall, supermarket outlets for fruits and vegetables are mostly located in urban and peri-urban areas. Linking these markets to smallholder farmers can bring multiple benefits: i) as producers, they can increase their incomes by selling to supermarkets at a good price, and ii) as consumers they will improve their nutrition status by consuming more fruits and vegetable. It should be noted that many smallholders, particularly in developing countries, will need support to enable them to build their technical and operational capacities to satisfy the requirements of highly competitive markets in terms of quantity and quality. Having done so, however, these farmers should also be able to enter other competitive markets, such as the fast food chains, food processors and exporters (Blandon, 2006).

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7. Conclusions and recommendations

7.1 CONCLUSIONS

The findings of this study are summarized below:

- Given low cropping intensity, a large part of the available water returns to the atmosphere as evaporation, rather than as transpiration, resulting in low water and land productivity Under prevailing conditions, there is no surplus from agriculture. Supply to industry and trade between rural areas and between rural and urban areas is hampered. Ethiopia is a net importer of food.
- A substantial part of the gap between actual and potential yield, for major crops in Ethiopia is related to water limitations. Erratic rainfall contributes to risk-averse of farmers, with implications for cropping patterns. About 75 percent of farmers produce just one or two crops, with maize as the most widespread staple.
- Yield varies significantly between cultivation seasons, farmers and crops. Notably, the range in yields is larger for fruits and vegetables than for cereals, pulses, legumes and oil crops. This is due to the typically high water sensitivity of fruits and vegetables. Increasing yields hinges on water management, including

harnessing rainwater, a range of good irrigation facilities and practices, and careful timing of operations and inputs, especially for water sensitive crops.

- With strategic support, high-value and nutrient-dense crops can be cultivated in farming and agro-pastoral systems, with potential benefits in terms of reduced malnutrition. In contexts where water is scarce and rainfall unreliable, it is important the nutritional water productivity should be relatively high for the crops under cultivation.
- Poor smallholders cannot easily switch from subsistence to other crops. Access to markets and/or procurement programmes may be a crucial driver for transforming agriculture and achieving nutrition goals.
- Ethiopia has made significant efforts to improve agricultural production capacity, in particular through investments in small, medium and large irrigation systems. There has been a dynamic expansion of micro-irrigation on smallholder farms; this can enable high marginal productivity from small amounts of supplementary water and stabilize yields in areas where the risk of dry spells is high. Additional benefits include the development of entrepreneurial skills and social recognition.
- Improvements in water management need to be combined with the use of fertilizers and improved seeds in a coordinated management strategy.
- The reliability of calculations for water, production, yields and nutrition depend on the quality of available data. Although data on rainfall and crop yields are typically available, accurate data around water and nutrition productivity are scarce. Efforts to gather such data should recognize that nutrition density varies with species and from field to fork. For vulnerable crops, the nutrition value as well as the palatability and price, may deteriorate rapidly after harvest, depending on logistical circumstances, e.g. transport and storage.

7.2 RECOMMENDATIONS

- Provide technical and institutional support for micro-irrigation to reduce risks and to stimulate the cultivation of crops with higher economic and nutritional values.
- Demonstrate the high marginal productivity of using supplementary water at low yield levels.
- Initiate hands-on demonstrations to show the benefits of better coordination and timing of water and other input uses, e.g. fertilizers and improved seeds.
- Design credit schemes and build the capacity of extension services to support the intensification and improved commercialization of crops identified through calculations of NWP and/or other means.
- Upgrade the nutrition knowledge of extension officers and farm households to increase their familiarity with the nutrient content of various food products.
- To guide policy efforts to reduce malnutrition, identify which nutrients are deficient in diets and what crops, or combination of crops contain a high density of these nutrients.
- Promote the cultivation of high-value crops and livestock in addition to staple crops.
- Link farmers to remunerative markets and public procurement of food initiatives, e.g. for school feeding programmes or hospitals, to stimulate the demand for high-value and nutrient-dense crops.

- Quality and validity of calculations, e.g. for policy, depend on assumptions and data quality. A number of potential improvements have been discussed in this report. For instance, more attention should be given to data and analyses of the erratic character of rainfall, its associated risks, and how to cope with the challenges; data on what has been referred to as farmer led irrigation would shed light on a dynamic part of agriculture and on the interface between rainfed and irrigated systems. It is important to overcome the fallacy of simple dichotomies between rainfed and irrigated agriculture.
- Ensure that management and conservation measures include activities that ensure the efficient and worthwhile use of available water.

References

Abrams, L. 2018. *Unlocking the potential of enhanced rainfed agriculture*. Report no. 39. Pages: 22. Stockholm, Stockholm International Water Institute (SIWI). (available at www.siwi.org/wp-content/uploads/2018/12/Unlocking-the-potential-of-rainfed-agriculture-2018-FINAL.pdf).

Adimassu, Z., Langan, S. & Barron, J. 2018. *Highlights of soil and water conservation investments in four regions of Ethiopia.* IWMI Working Paper 182. Colombo, International Water Management Institute (IWMI). 35p. doi: 10.5337/2018.214.

Assefa, S., Biazin, B., Muluneh, A., Yiemr, F. & Haileslassie, A. 2016. Rainwater harvesting for supplemental irrigation of onions in the southern dry lands of Ethiopia. *Agricultural Water Management*, 178: 325-334. doi: 10.1016/j.agwat.2016.10.012.

Atnaf, M., Tesfaye, K., & Kifle, D. 2015. The importance of legumes in the Ethiopian farming system and overall economy: an overview. *American Journal of Experimental Agriculture*, *7*(6), 347-358.

Awulachew, S.B., Erkossa, T. & Namara, R. 2010. *Irrigation potential in Ethiopia: constraints and opportunities for enhancing the system.* Colombo, IWMI. (available at www.researchgate.net/publication/255485328_Irrigation_potential_in_Ethiopia_Constraints_and_opportunities_for_enhancing_the_system).

Bachewe, F., Hirvonen, K., Minten,B. & Yimer, F. 2017. *The rising costs of nutritious foods in Ethiopia.* ESSP Research note 67 June. 4 pp. Ethiopia Strategy Programme, EDRI (Ethiopia Development Research Institute), IFPRI (International Food Policy Research Institute) (available at www.ifpri.org/publication/rising-costs-nutritious-foods-ethiopia).

Baye, K. 2014. *Teff: nutrient composition and health benefits*. Ethiopia Strategy Support Programme, Working paper 67. EDRI (Ethiopia Development Research Institute), IFPRI (International Food Policy Research Program). (available at http://cdm15738.contentdm.oclc.org/utils/getfile/collection/p15738coll2/id/128334/filename/128545.pdf).

Baye, K., Hirvonen, K., Dereje, M. & Remans, R. 2019. Energy and nutrient production in Ethiopia, 2011-2015: Implications to supporting healthy diets and food systems. *PLOS One,* 14(3): 12 [online]. [Cited 21 April 2020] doi: https://doi.org/10.1371/journal.pone.0213182.

Bekele, S. & Tilahun, K. 2007. Regulated deficit irrigation scheduling of onion in a semiarid region of Ethiopia. *Agricultural Water Management*. 89:148-152. doi: 10.1016/j.agwat.2007.01.002.

Bekele, S.B., Erkossa, T. and Namara, R. 2010. *Irrigation potential in Ethiopia. Constraints and opportunities for enhancing the system.* Colombo, IWMI. (available at www.researchgate.net/publication/255485328).

Belachew, T., Hadley, C., Lindstrom, D., Gebremariam, A., Lachat, C., & Kolsteren, P. 2011. Food insecurity, school absenteeism and educational attainment of adolescents in Jimma Zone, Southwest Ethiopia: a longitudinal study. *Nutrition Journal*, 10(1), 29.

Belete, Y., Birru, E., Kebede, H. 2011. *Small-scale irrigation situation, analysis and capacity needs assessment*. WOCAT. Eds. GIZ, Germany, Ministry of Agriculture, Ethiopia and Israel's Agency for Development Cooperation. (available at https://wocatpedia.net/wiki/Small-Scale_Irrigation_Analysis_and_Capacity_Needs_Assessment).

Blandon, J. 2006. *Supermarket supply chain for fresh fruits and vegetables: opportunities and challenges for small farmers*. Faculty of Graduate Studies, University of Guelph (PhD dissertation). pp 206. (available at https://idl-bnc-idrc.dspacedirect.org/bitstream/handle/10625/26849/123351.pdf).

Blas, A., Garrido, A., Unver, O. & Willaarts, B. 2019. A comparison of the Mediterranean diet and current food consumption patterns in Spain from a nutritional and water perspective. *Science of the Total Environment,* 664: 1020-1029. doi: 10.1016/j.scitotenv.2019.02.111.

Brouwer, C. & Heibloem, M. 1986. *Irrigation water management: irrigation water needs*. Training manual No. 3. Rome, FAO. (available at www.fao.org/3/S2022E/s2022e00.htm).

Bryan, E., Chase, C. & Schulte, M. 2019. *Nutrition-sensitive irrigation and water management*. Washington, DC, World Bank. 34 pp. (available at https://wle.cgiar.org/nutrition-sensitive-irrigation-and-water-management).

Central Statistical Agency (CSA). 2016. Agricultural sample survey 2015/16 (2008 E.C.). Volume 1, Report on area and production of major crops, private peasant holdings for Meher season. [Cited April 21, 2020] *Statistical Bulletin 584*. Addis Ababa.

CSA. 2017. Agricultural sample survey 2016/17 (2009 E.C.). Volume 1, Report on area and production of major crops, private peasant holdings for Meher season. [Cited April 21, 2020] *Statistical Bulletin 584*. Addis Ababa.

CSA. 2018. *Agricultural sample survey 2017/18 (2010 E.C.)*. Volume 1, Report on area and production of major crops, private peasant holdings for Meher season. *Statistical Bulletin 586*. Addis Ababa.

Chibarabada, T.P., Modi, A.T. & Mabhaudhi, T. 2017. Nutrient content and nutritional water productivity of selected grain legumes in response to production environment. *International Journal of Environmental Research and Public Health*, 14(11):1300. doi:10.3390/ijerph14111300.

Cochrane, L., & Bekele, Y.W. 2018. Contextualizing narratives of economic growth and navigating problematic data: economic trends in Ethiopia (1999–2017). *Economies*, 6(4): 64. (available at www.mdpi.com/2227-7099/6/4/64/htm).

Critchley, W. & Siegert, K. 1991. *Water harvesting – a manual for the design and construction of water harvesting schemes for plant production*. Rome, FAO. (available at www.samsamwater.com/library/Water_harvesting_-_Critchley.pdf).

Damerau, K., Waha, K. & Herrero, M. 2019. The impact of nutrient-rich food choices on agricultural water-use efficiency. *Nature Sustainability*, 2: 233-241. (available at www.nature.com/articles/s41893-019-0242-1).

Derib, S.D., Descheemaeker, K., Haileslassie, A., & Amede, T. 2011. Irrigation water productivity as affected by water management in a small-scale irrigation scheme in the Blue Nile Basin, Ethiopia. *Experimental Agriculture*, 47(S1): 39-55. (available at www.cambridge.org/core/journals/experimental-agriculture/article/irrigation-water-productivity-as-affected-by-water-management-in-a-smallscale-irrigation-scheme-in-the-blue-nile-basin-ethiopia/A5781767BF68060D94F1869FC73F0C08).

Descheemaeker, K., Bunting, S.W., Bindraban, P., Muthuri, C., Molden, D., Beveridge, M., van Brakel, M., *et al.*, 2013. Increasing water productivity in agriculture. In: Boelee, E., ed. *Managing Water and Agroecosystems for Food Security*. Comprehensive Assessment of Water Management in Agriculture Series 10. (available at www.iwmi.cgiar.org/Publications/CABI_Publications/CA_CABI_Series/Managing_Water_and_Agroecosystems/managing_water_for_agroecosystems_and_food_security.pdf).

Domènech, L. 2015. Improving irrigation access to combat food insecurity and undernutrition: a review. *Global Food Security*, 6:24-33.

Doorenbos, J. & Pruitt, W.O. 1992. *Crop water requirements*. Irrigation and Drainage Paper 26. Rome, FAO.

Edossa, D.C. & Gadissa Emana, T. 2011. Interaction effects of drip irrigation level and planting method on water use efficiency, irrigation uniformity and yield in green pepper (Capsicum annuum L.). *Philippine Agricultural Scientist*, 94(4): 350-358.

Eguavoen, I., Derib, S.D., Deneke, T.T., McCartney, M., Otto, B.A., & Billa, S.S. 2012. Digging, damming or diverting? Small-scale irrigation in the Blue Nile Basin, Ethiopia. *Water Alternatives*, 5(3): 678-699 www.researchgate.net/publication/259214434_Digging_damming_or_diverting_Small-scale_irrigation_in_the_Blue_Nile_Basin_Ethiopia.

Erkossa, T., Menker, M. & Betrie, G.D. 2010. Effects of bed width and planting date on water productivity of wheat grown on vertisols in the Ethiopian Highlands. *Irrigation and Drainage*.6(5) 635-643]. doi: 10.1002/ird.608 (available at https://onlinelibrary.wiley.com/doi/full/10.1002/ird.608).

Erkossa, T., Awlachew, S. & Aster, D. 2011. Soil fertility effect on water productivity of maize in the upper Blue Nile Basin, Ethiopia. *Agricultural Sciences*, 2(3): 238-247. doi:10.4236/as.2011.23032

Erkossa, T., Awlachew, S., Hailesselassi, A. & Denekew, A. 2019. *Impacts of improving water management of smallholder agriculture in the Upper Blue Nile Basin.* IWMI Conference Proceedings 212433. (available at www.researchgate.net/publication/334671056_Impacts_of_Improving_Water_Management_of_Smallholder_Agriculture_in_the_Upper_Blue_Nile_Basin_CP_19_Project_Workshop_Proceedings_7_Impacts_of_Improving_Water_Management_of_Smallholder_Agriculture_in_t).

Ethiopian Institute of Agricultural Research. *Agricultural Growth Programme-II (AGP2).* Addis Ababa. (available at www.eiar.gov.et/index.php/agricultural-growth-programme-ii).

Ethiopia Public Health Institute. 2013. *Ethiopia National Food Consumption Survey*. Addis Ababa. (available at www.ephi.gov.et/images/pictures/National%20Food%20Consumption%20Survey%20Report_Ethiopia.pdf).

European Commission (EC). 2020. Ethiopia Nutrition Country. https://ec.europa.eu/europeaid/sites/devco/files/nutrition-fiche-ethiopia-2016_en.pdf. (Accessed, August 25, 2020) [Cited 21 April 2020].

Food and Agriculture Organization of the United Nations (FAO). 2012a. Family farming knowledge platform. In: *Food and Agriculture Organization of the United Nations* [online]. [Cited 20 February 2019]. Rome. www.fao.org/family-farming/data-sources/dataportrait/country-details/en/?cnt=ETH

FAO. 2013. Food security indicators. In: *Food and Agriculture Organization of the United Nations* [online]. [Cited 20 February 2019]. www.fao.org/publications/sofi/food-security-indicators/en/.

FAO. 2012b. AQUAMAPS – Global spatial database on water and agriculture: global map of monthly reference evapotranspiration (year) – 10 arc minutes [online]. In: *Food and Agriculture Organization of the United Nations*. Rome. [Cited 20 February 2019]. www.fao.org/nr/water/aquamaps/.

FAO. 2016. AQUASTAT country profile – Ethiopia [online]. In: *Food and Agriculture Organization of the United Nations* [online]. Rome. [Cited 5 March 2020]. www.fao.org/3/i9732EN.pdf.

FAO. 2017. *The future of food and agriculture – trends and challenges*. Rome. [Cited 20 February 2019].

FAO. 2019a. *Climate-smart agriculture* [online]. In: *Food and Agriculture Organization of the United Nations.* Rome. [Cited 20 February 2019]. www.fao.org/climate-smart-agriculture/en/.

FAO. 2019b. *Land, water and the SDGs* [online]. In: *Food and Agriculture Organization of the United Nations.* Rome. [Cited 3 January 2019]. www.fao.org/land-water/overview/land-water-sdg/en/.

FAO. 2019c. *Food-based dietary guidelines* [online]. In: *Food and Agriculture Organization of the United Nations.* Rome. [Cited 14 March 2019]. www.fao.org/nutrition/education/food-dietary-guidelines/regions/africa/en/.

FAO/World Health Organization (WHO). 1998. *Carbohydrates in human nutrition.* Food and Nutrition Paper 66. Rome, FAO.

FAO/WHO. 2018. *Strengthening nutrition action – a resource guide for countries based on the policy recommendations of the Second International Conference on Nutrition (ICN2).* Rome, FAO.

FAO/Government of Kenya. 2018. Kenya Food Composition Tables. Nairobi. 254 pp. [Cited 20 February 2019]. (available at www.fao.org/3/I9120EN/i9120en.pdf).

FAO, International Fund for Agricultural Development (IFAD) & World Food Programme (WFP). 2013. *The State of Food Insecurity in the World 2013. The multiple dimensions of food security.* Rome, FAO.

FAO, IFAD, UNICEF, WFP & WHO. 2018. *The State of Food Security and Nutrition in the World 2018. Building climate resilience for food security and nutrition*. Rome, FAO.

FAO, IFAD, UNICEF, WFP & WHO. 2019. *The State of Food Security and Nutrition in the World 2019. Safeguarding against economic slowdowns and downturns.* Rome, FAO.

FAO. 2013. Nutrition and Food Systems Division/Meeting Programming and Documentation Service, FAO, 2013 (MI198) adapted from Briefing Paper, Bread for the World Institute, Number 20, 2012. (available at www.bread.org/institute/papers/nutrition-sensitive-interventions.pdf).

FAO/Republic of Kenya. 2018. *Kenya Food Composition Tables*. Nairobi, FAO. 254 pp. [Cited 20 February 2019]. (available at www.fao.org/3/19120EN/i9120en.pdf).

Federal Democratic Republic of Ethiopia. 2002. *Food Security Strategy*. Addis Ababa.

Federal Democratic Republic of Ethiopia. 2011. *Ethiopia's climate-resilient green economy: green economy strategy*. Addis Ababa. 188 pp. (available at www.greengrowthknowledge.org/national-documents/ethiopia's-climate-resilient-green-economy-green-economy-strategy).

Feed the Future. 2018. *Global Food Security Strategy – Ethiopia Country Plan*. The US Government's Global Hunger & Food Security Initiative. (available at www.usaid.gov/sites/default/files/documents/1867/Ethiopia_GFSS_Country_Plan_WS_Edits_9.21.pdf).

Gebremedhin, B. & Jaleta, M. 2012. *Market orientation and market participation of smallholders in Ethiopia: implications for commercial transformation*. Selected Paper prepared for presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference, Foz do lguacu, Brazil, 18-24 August, 2012. [Cited 4 September 2020]. (available at www.researchgate.net/publication/254387361_Market_Orientation_and_Market_Participation_of_Smallholders_in_Ethiopia_Implications_for_Commercial_Transformation).

Gebremedhin, T. 2015. Effect of drip and surface irrigation methods on yield and water use efficiency of onion (Allium cepa. L.) under semi-arid condition of Northern Ethiopia. *Journal of Biology, Agriculture and Healthcare*, 5(14) 88-94.

Gebremedhin, Y., Berhe, A. & Nebiyu, A. 2015. Performance of AquaCrop model in simulating tuber yield of potato (Solanum tuberosum L.) under various water availability conditions in Mekelle area, Northern Ethiopia. *Journal of Natural Sciences Research*. 5(5): 123-131.

Gebru, M., Remans, R., Brouwer, I., Baye, K., Melesse, M.B., Covic, N., Habtamu, F. *et al.*, 2018. Pages: 51. Food systems for healthier diets in Ethiopia – toward a research agenda. Discussion Paper 01720. Washington, DC, International Food Policy Research Institute (IFPRI). (available at www.ifpri.org/publication/food-systems-healthier-diets-ethiopia-toward-research-agenda).

Gelaw, A., Bellete, T., Kasahun B. Demiss, M. 2018. Recent developments in soil fertility mapping and fertilizer advisory services in Ethiopia – ATA-MoANR joint position paper. Paper presented at the National Consultative Workshop, Adama, Ethiopia, March 2018. (available at www.researchgate.net/publication/327764748_Recent_Developments_in_Soil_Fertility_Mapping_and_Fertilizer_Advisory_Services_in_Ethiopia_A_Position_Paper).

Gezahegn, A., Gemechu, A., Kiflu, G., Mekonnen, B., Tilahun, H. & Kdane, G. 2006. *Water harvesting practices and impacts on livelihood outcomes in Ethiopia.* Addis Ababa, EDRI.

Gudissa, H.D. & Edossa, D.C. 2014. Evaluation of surge and cutback flow furrow irrigation systems for pepper (Capsicum annum) production. *Irrigation and Drainage*, 63(4): 463-473.

Gutema, P., Medhin, H., Woubshet, D., Amare, S. & Wakeyo, M.B. 2017. *Impact of climate change on Ethiopian agriculture*. Research Report. Addis Ababa, Environmental Centre for Climate Research.

Guush, B., Paulos, Z., Tafere, K., & Tamru, S. 2011. *Food grain consumption and calorie intake patterns in Ethiopia.* Pages: 18. IFPRI Ethiopia Strategy Support Programme II Working Paper 23. Washington, DC, IFPRI.

Haileslassie, A., Peden, D., Gebreselassie, S., Amede, T. & Descheemaeker, K. 2009. Livestock water productivity in mixed crop-livestock farming systems of the Blue Nile basin: assessing variability and prospects for improvements. *Agricultural Systems*. vol. 102(1-3): 33-40. doi: 10.1016/j.agsy.2009.06.006.

Hailu, E.K., Urga, Y.D., Sori, N.A., Borona, F.R. & Tufa, K.N. 2018. Sesame yield response to deficit irrigation and water application techniques in irrigated agriculture, Ethiopia. *International Journal of Agronomy*. doi: 10.1155/2018/5084056.

International Livestock Center for Africa (ILCA). 1993. *The Borana Plateau of southern Ethiopia: synthesis of pastoral research, development and change, 1980-91.* Addis Ababa. (available at cgspace.cgiar.org/bitstream/handle/10568/4660/ILCA_SS_5_1.pdf?sequence=1&isAllowed=y).

International Fertilizer Development Center (IFDC). 2015. *Assessment of fertilizer consumption and use by crop in Ethiopia.* Muscle Shoals, Alabama, USA.

Jalava, M. 2019. *The water we eat. Methods for estimating water use of diets in changing food systems*. Espoo, Finland, Aalto University (PhD dissertation). (available at https://aaltodoc.aalto.fi/handle/123456789/39595).

Jiru, M. & Van Ranst, E. 2010. Increasing water productivity on vertisols: implications for environmental sustainability. *Journal of the Science of Food and Agriculture*, 90(13): 2276-2281. doi: 10.1002/jsfa.4082.

Kassu, T., Tilahun, H., Yared, D. & Watanabe, H. 2017. Effect of irrigation regimes on yield and water use efficiencies of potato. *International Journal of Plant Production*, 11(3): 1735-6814. doi: 10.22069/ijpp.2017.3547.

Kifle, M. & Gebretsadikan, T.G. 2016. Yield and water use efficiency of furrow irrigated potato under regulated deficit irrigation, Atsibi-Wemberta, North Ethiopia. *Agricultural Water Management*, 170: 133-139. doi: 10.1016/j.agwat.2016.01.003.

Kiran, C., Siddiqui, S., Barron, J., Subasinghe, C. & Haileslassie, A. 2018. *Ecological footprint of food security: mapping irrigated area in Ethiopia.* Presentation to Ethiopian Agricultural Transformation Agency (ATA). Addis Ababa. (available at www.researchgate.net/publication/325594118_Ecological_footprint_of_food_security_mapping_irrigated_area_in_Ethiopia).

Krishna Bahadur, K.C., Id, K., Goretty, M., Dias, G., Veeramani, A., Swanton, C., Fraser, D., Steinke, D., Lee, E., Wittman, H. *et al.*, 2018. When too much isn't enough: Does current food production meet global nutritional needs? *PLOS One,* 13(10): e0205683 [online] [Cited 21 April 2020] doi: https://doi.org/10.1371/journal.pone.0205683.

Lefore, N., Giordano, M., Ringler, C. & Barron, J. 2019. Sustainable and equitable growth in farmer-led irrigation in sub-Saharan Africa: what will it take? *Water Alternatives,* (12)1: 156-168.

Lukmanji Z., Hertzmark E., Mlingi N., Assey V., Ndossi G., Fawzi W. 2008. *Tanzania food composition Tables*. MUHAS- TFNC, HSPH, Dar es Salaam Tanzania. https://cdn1.sph.harvard.edu/wp-content/uploads/sites/30/2012/10/tanzania-food-composition-tables.pdf

Lundqvist, J. & Unver, O. 2018. Alternative pathways to food security and nutrition – water predicaments and human behavior. *Water Policy*, 20(5): 871-884. doi: 10.2166/wp.2018.171.

Lundqvist, J. 2019. *The wind is blowing for water*. [online] [Cited 20 February 2019]. (available at www.siwi.org/latest/the-wind-is-blowing-for-water/).

Malmquist, L. 2018. *Water productivity and water requirements in food production – examples from Ethiopia, Tanzania and Burkina Faso.* Uppsala, Sweden, Swedish University of Agricultural Sciences, Department of Soil and Environment.

McKevith, B. 2004. Nutritional aspects of cereals. *Nutrition Bulletin*, 29: 111-142. (available at www.nutrition.org.uk/attachments/207_Nutritional%20aspects%20of%20cereals.pdf).

Mekonnen, S., Descheemaeker, K., Tolera, A. & Amede, T. 2011. Livestock water productivity in a water stressed environment in Northern Ethiopia. *Experimental Agriculture*, 47(1): 85-98. doi: 10.1017/S0014479710000852.

Ministry of Finance and Economic Development (MoFED), Federal Democratic Republic of Ethiopia. 2010. *Growth and Transformation Plan/GTP I*. Draft. September. Addis Ababa. 85 pp. (available at www.ethiopians.com/Ethiopia_GTP_2015.pdf).

Molden, D., **ed**. 2007.*Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. London, Earthscan, and Colombo, International Water Management Institute. 645 pp.

Mottet,A., de Haan, C., Falcucci, A., Tempio, G., Opio, C. and Gerber, P. 2017. Livestock: on our plates or eating at our table? A new analysis of the feed/food debate. *Global Food Security*, 14: 1-8.

Mutema, M., Mbava, N., Zengeni, R., Shimelis, H. & Chaplot, V. 2019. Factors affecting crop water use efficiency: A worldwide meta-analysis. *Agricultural Water Management*. doi: 228. 10.1016/j.agwat.2019.105878.

Nelson, G., Bogard, J., Lividini, K., Arsenault, J., Riley, M., Sulser, T.B., Mason-Dçroz, D. *et al.*, 2018. Income growth and climate change effects on global nutrition security to mid-century. *Nature Sustainability*, 1: 773-781. doi: 10.1038/s41893-018-0192-z.

Nyathi, M.K., Van Halsema, G.E., Beletse, Y.G., Annandale, J.G. & Struik, P.C. 2018. Nutritional water productivity of selected leafy vegetables. *Agricultural Water Management*. 209: 111-122. doi: 10.1016/j.agwat.2018.07.025.

Pinstrup-Andersen, P. 2018. How to guide food systems to achieve nutrition objectives. In: *The World Food Prize, the Borlaug Blog*. (available at www.worldfoodprize.org/index.cfm/88533/18102/how_to_guide_food_systems_to_achieve_nutrition_objectives).

Policy Study Institute. 2019. *Second Agricultural Growth Programme (AGP II) midterm quantitative impact evaluation report.* Addis Ababa. (available at www.bing.com/search?q=Second+Agricultural+Growth+Programme+%28AGP+II%29+midterm+quantitative+impact+evaluation+report.&form=EDGSPH&refig=808855cff3864e6fbb0cb16d8043463b&mkt=en-us&msnews=1&PC=LCTS&sp=-1&pq=second+agricultural+growth+programme+%28a).

Poole, N. 2017. *Smallholder agriculture and market participation*. 172 pp. Rugby, UK, Practical Action Publishing]. [Cited 20 February 2019] doi: http://dx.doi.org/10.3362/9781780449401.

Renault, D. & Wallender, W.W. 2000. Nutritional water productivity and diets: from 'crop per drop' towards 'nutrition per drop. *Agriculture Water Management*, 45: 275-296.

Ringler, C., Zhu, T., Gruber, S., Treguer, R., Auguste, L., Addams, L., Cenacchi. N. *et al.*, 2016. Role of water security for agricultural and economic development – concepts and global scenarios. In: C. Pahl-Wostl, J. Gupta and A. Bhaduri, eds. *Handbook on water security*. Aldershot, Edward Elgar Publishing Ltd. 384 pp.

Rockström, J. & Barron, J. 2007.Water productivity in rainfed systems: overview of challenges and analysis of opportunities in water scarcity-prone savannahs. *Irrigation Science*, 25: 299-311. doi: 10.1007/s00271-007-0062-3.

Schmitter, P., Kefyalew, S.K., Lefore, N. & Barron, J. 2018. Suitability mapping framework for solar photovoltaic pumps for smallholder farmers in sub-Saharan Africa. *Applied Geography,* 94:41-57. doi: https://doi.org/10.1016/j.apgeog.2018.02.008.

Seyoum Taffesse, A., Dorosh, P. & Asrat, S. 2011. Crop Production in Ethiopia: Regional Patterns and Trends.ESSP II Working Paper 16, Development Strategy and Governance Division, International Food Policy Research Institute, Ethiopia Strategy Support Program II, Ethiopia. https://www.ifpri.org/publication/crop-production-ethiopia-regional-patterns-and-trends

Sheahan. M. & Barrett, C.B. 2017. Ten striking facts about agricultural inputs in sub-Saharan Africa. *Food Policy*, 67: 12-25. doi: http://dx.doi.org/10.1016/j.foodpol.2016.09.010.

Spielman, D.J., Kelemwork, D. & Alemu, D. 2011. *Seed, fertilizer, and agricultural extension in Ethiopia.* Ethiopia Strategy Support Programme (ESSP II) Working Paper 020. Addis Ababa, IFPRI (International Food Policy Research Institute) and EDRI (Ethiopia Development Research Institute), (available at http://essp.ifpri.info/files/2011/02/ESSP2_WP20_SeedFertilizerAgrExtensionEthiopia.pdf).

Stadlmayr, B., Charrondiere, U.R., Enujiugha, V.N., Bayili, R.G., Fabohoun, E.G., Samb, B., Addy, P., *et al.*, 2012. *West African Food Composition Tables*. Rome, FAO, INFOODS, WAHO and Biodiversity International. (available at www.fao.org/3/i2698b/i2698b00.pdf).

Steduto. P., Hsiao, T.C., Fereres, E. & Raes, D. 2012. *Crop yield response to water*. FAO Irrigation and drainage paper 66. Pages: 500. Rome, FAO. (available at www.fao.org/3/i2800e/i2800e.pdf).

Swaminathan, M.S. and Bhavani, R.V. 2013. Food production & availability - Essential prerequisites for sustainable food security. *Indian Journal of Medical Research*, 138(3): 383–391. (available at www.ncbi.nlm.nih.gov/pmc/articles/PMC3818607/).

Tamene, L., Amede, T., Kihara, J., Tibebe, D. & Schultz, S., eds. 2017. *A review of soil fertility management and crop response to fertilizer application in Ethiopia: towards development of site- and context-specific fertilizer recommendations*. Addis Ababa, International Center for Tropical Agriculture (CIAT). 86 pp. (available at http://hdl.handle.net/10568/82996).

Teklay, G. & Ayana, M. 2014. Evaluation of irrigation water pricing systems on water productivity in Awash River Basin, Ethiopia. *Journal of Environment and Earth Science*, 4(7): 70-77.

Tsegaye, D., Vedeld, P. & Moe, S.R. 2013. Pastoralists and livelihoods: a case study from northern Afar, Ethiopia. *Journal of Arid Environments*, 91:138-146.

Tsegaye, D., Verhees, F.J.H.M & van Trijp, H.C.M. 2017. Seed producer cooperatives in the Ethiopian seed sector and their role in seed supply improvement: a review. *Journal of Crop Improvement*, 31(3): 323-355. doi: 10.1080/15427528.2017.1303800.

Uganda National Meteorological Authority (UNMA). 2016. *Water requirements from some selected crops.* Kampala.

UN Standing Committee on Nutrition (UNSCN). 2019. *Water and nutrition: harmonizing actions for the United Nations decades* (discussion paper) (available at www.ifpri.org/publication/water-and-nutrition-harmonizing-actions-united-nations-decade-action-nutrition-and).

United States Department of Agriculture (USDA). USDA Nutrient Database In *USDA National Agricultural Library* [online]. Washington, DC. www.nal.usda.gov/fnic/food-composition.

Wageningen University & Research/University of Nebraska, Lincoln. 2019. *Global Yield Gap Atlas* [online]. Cited 20 February 2019]. www.yieldgap.org/gygamaps/app/index.html.

Yigrem, S., Beyene, F., Tegegne A. and Gebremedhin, B. 2008. *Dairy production, processing and marketing systems of Shashemene–Dilla area, South Ethiopia.* IPMS (Improving Productivity and Market Success) of Ethiopian Farmers Project Working Paper 9. Nairobi, International Livestock Research Institute (ILRI). 62 pp.

Yihun, Y.M., Haile, A.M., Schultz, B. & Erkossa, T. 2013. Crop water productivity of irrigated teff in a water stressed Region. *Water Resource Management*, 27. 3115–312. doi: 10.1007/s11269-013-0336-x.

Van Halsema, G.E., Lencha, B.K., Assefa, M., Hengsdjik, H. & Wesseler, J. 2012. Performance assessment of smallholder irrigation in the central rift valley of Ethiopia. *Irrigation and drainage.* Vol. 60(5):622-634. doi: https://doi.org/10.1002/ird.613.

Wakeyo, M.B. & Gardebroek, C. 2015. Empty pockets, empty ponds? Disadoption of water harvesting technologies in Ethiopia. *Journal of Arid Environments*, 120: 75-86.

Wakeyo, M.B., Shumi, S. & Oka, N. 2016. Financial constraint to irrigation expansion in Ethiopia and alternative strategies from Asian experience. Paper No W.3.2.02 presented at the 2nd World Irrigation Forum, 6-8 November 2016, Chiang Mai, Thailand.

Wakeyo, M.B. & Gardebroek, C. 2017. Share of irrigated land and farm size in rainwater harvesting irrigation in Ethiopia. *Journal of Arid Environments*. 139: 85-94. doi: 10.1016/j.jaridenv.2017.01.002.

Wakeyo, M.B., Kuma, T., Mekonnen, B., & Ageba, G. 2018. *Agricultural Growth Programme II: baseline survey final report.* Addis Ababa, EDRI.

Werfring, A., Lempérière, P. & Boelee, E. 2004. Typology of irrigation in Ethiopia. In: *Proceedings of Inception workshop on IWMI-BOKU-Siebersdorf-EARO-Arbaminch University collaborative study on the impact of irrigation development on poverty and the environment,* 26-30 April 2004, Addis Ababa.

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen,, S., Garnett., T. *et al.*, 2019. Food in the anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet*, 393(10170): 447-492.

World Bank. 2015. The State of Social Safety Nets 2015, Washington, DC 20433, 166p. (available at http://documents1.worldbank.org/curated/en/415491467994645020/pdf/97882-PUB-REVISED-Box393232B-PUBLIC-DOCDATE-6-29-2015-DOI-10-1596978-1-4648-0543-1-EPI-1464805431.pdf)

World Food Programme/Purchase for Progress (WFP/P4P). 2014. *Supporting public procurement from smallholder farmers.* P4P Global Learning Series. Rome.

WFP. 2013. *The State of School Feeding Worldwide 2013*. School Feeding Service. Rome.

WFP. 2009. *Home-grown school feeding: a framework to link school feeding with local agricultural production.* School Feeding Service. Rome

WFP. 2007. *School feeding handbook: guide for programme managers*. School Feeding Service. Rome.

WFP (undated, a). *Home grown school feeding* [online]. Rome. [Cited 23 April 2019]. https://www1.wfp.org/home-grown-school-feeding.

WFP. (undated, b) *Benin* [online]. Rome. [Cited 23 April 2019]. www1.wfp.org/countries/benin.

WFP. (undated, c). *Ghana prepares school feeding bill* [online]. Rome. [Cited 23 April 2019]. https://docs.wfp.org/api/documents/WFP-0000108072/download/?_ga=2.53020014.738415222.1599470846-2005537752.1596544036

WHO, FAO & United Nations University (UNU). 2007. *Protein and amino acid requirements in human nutrition – report of a joint WHO/FAO/UNU expert consultation*. WHO Technical Report Series; no. 935. Geneva, WHO.

Appendix A

TABLE 2
Values for evapotranspiration of crops commonly produced in Ethiopia. The values are global intervals, except the values from the Uganda National Meteorological Authority, which are used as a comparison to conditions relevant to Ethiopia and to validate the global intervals to calculate estimates of nutritional water productivity in Ethiopia

Reference	Doorenbos and Pruitt, 1992	Uganda National Meteorological Authority, 2016	Critchley and Siegert, 1991	Steduto *et al.*, 2012	Brouwer and Heibloem, 1986
Maize	400–750	500–800		500–800	500–800
Rice	500–950			800–1100	450–700
Sorghum	300–650	450–650		450–750	450–650
Millet					450–650
Barley				100–500	450–650
Wheat				200–500	450–650
Teff				450–550	
Oats					450–650
Potatoes	350–625	500–700		350–650	500–700
Sweet potatoes	400–625				
Onions	350–600				350–550
Beans	250–500	300–500	300–500		300–500
Pea					350–500
Soybean	450–825		450–650	300–800	450–700
Oil seeds	300–600				
Groundnut			500–700		500–700
Bambara groundnut				500–600	
Sunflower		600–1 000	600–1 000	450–800	600–1 000
Vegetables	250–500				
Tomato	300–600	400–600		400–800	400–800
Cabbage					350–500
Pepper					600–900
Citrus					900–1 200
Banana					800–1 600

TABLE 3
Values for water productivity of crops commonly produced in Ethiopia

CROP	WP_{RAIN}	WP_{IRR}	REFERENCE
	WP=Y/Etc [kg m^{-3}]	WP=Y/Etc [kg m^{-3}]	
Barley	0.41		Haileslassie *et al.,* 2009
Wheat	0.21; 0.23		Haileslassie *et al.,* 2009
		0.32; 0.76; 1.08	Derib *et al.,* 2011
Durum wheat		0.48; 0.53; 0.56; 0.63; 0.66	Erkossa, Menker, and Betrie, 2010
Maize	0.36		Haileslassie *et al.,* 2009
		0.41	Mekonnen *et al.,* 2011
		0.53; 0.71; 1.43; 1.55; 1.58; 1.72	Jiru and Van Ranst, 2010
Sorghum	0.24		Haileslassie *et al.,* 2009
		0.33	Mekonnen *et al.,* 2011
Millet	0.38		Haileslassie *et al.,* 2009
Rice		0.67	Haileslassie *et al.,* 2009
Teff	0.24; 0.33		Haileslassie *et al.,* 2009
		0.23	Mekonnen *et al.,* 2011
		0.4; 1.08; 1.49	Derib *et al.,* 2011
		0.42; 0.60; 0.64; 0.67; 0.68; 0.71; 0.73; 0.73; 0.74; 0.75; 0.75; 0.78; 0.79; 0.80; 0.80; 0.82; 0.87; 0.87; 0.87; 0.89; 0.92; 0.92; 0.92; 0.93; 0.93; 0.93; 0.96; 0.96 0.96; 0.97; 0.97; 0.98; 0.98; 1.01; 1.01; 1.04; 1.05; 1.07; 1.08; 1.08; 1.08; 1.08; 1.09; 1.11; 1.11; 1.12; 1.12; 1.16	Yihun *et al.,* 2013
Potato	2.37; 2.52		Gebremedhin, Berhe, and Nebiyu, 2015
		1.45; 1.46	Haileslassie *et al.,* 2009
		1.6; 1.81; 1.88; 2.09; 2.30; 2.71; 2.79; 2.86	Kifle and Gebretsadikan, 2016
		2.93; 3.03; 3.83	Gebremedhin, Berhe, and Nebiyu, 2015
Potato		6.846; 8.858; 8.984; 9.030; 9.427; 12.016; 13.140; 13.533; 13.681; 13.999; 17.179; 19.873	Kassu, *et al.,* 2017
Garlic		1.15	Haileslassie *et al.,* 2009

CROP	WP_{RAIN}	WP_{IRR}	REFERENCE
	WP=Y/Etc [kg m^{-3}]	WP=Y/Etc [kg m^{-3}]	
Onion	1.91		Assefa *et al.*, 2016
		1.385	Teklay and Ayana, 2014
		1.52; 1.78	Derib *et al.*, 2011
		1.76	Haileslassie *et al.*, 2009
		2.02; 2.31; 2.35; 2.80; 3.60; 4.30	Assefa et al., 2016
		5.6	Gebremedhin, 2015
		7.88	Bekele and Tilahun, 2007
		8.3; 8.6; 8.9	Gebremedhin, 2015
		8.96; 8.99; 9.54; 9.70; 9.85; 10.0; 10.18	Bekele and Tilahun, 2007
Pulses	0.18; 0.68		Haileslassie *et al.*, 2009
Chickpea		0.21	Mekonnen *et al.*, 2011
Sesame seed		0.994; 1.068; 1.114; 1.121; 1.166; 1.203; 1.231; 1.555; 1.654	Hailu *et al.*, 2018
Green pepper	0.50; 0.63; 1.20; 1.75; 1.94; 2.18; 2.53		Gudissa and Edossa, 2014
	3.96		Edossa and Gadissa Emana, 2011

TABLE 4

Nutrient content per 100 g for main crops grown in Ethiopia. The values are mainly from the food composition tables in EPHI, 2013. Where values were missing in EPHi (2013), these have been complemented with values from Baye, 2014; Lukmanju and Hertzmark, 2008; FAO/Government of Kenya, 2018; FAO, 2012; USDA (undated). The nutrition values are for dry, raw grains and oil crops. Where applicable, values for pulses and legumes were estimated as an average between dry and fresh where the food intake is divided over the two forms. Nutrition values for roots and tubers, vegetables and fruit are valid for raw and fresh food items

	COMPOSITION IN TERMS OF 100 GRAMS EDIBLE PORTION																				
	Energy	Carbohydrates (incl. fiber)	Protein	Fat	Fiber	Calcium	Phosphorous	Iron	Zinc	Copper	Potassium	Magnesium	Sodium	-carotene Equiv.	Thiamine	Riboflavin	Niacin	Vitamin C: total ascorbic acid	Vitamin B6	Folate(total)	Vitamin E	Vitamin K
	[kcal 100 g^{-1}]	[g 100 g^{-1}]	[g 100 g^{-1}]	[g 100 g^{-1}]	[g 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[µg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[µg 100 g^{-1}]	[mg 100 g^{-1}]	[µg 100 g^{-1}]
Teff (average)	357	80	9.5	2.5	3	180	429	7.63	3.63	1.6	427	184	12	0	0.39	0.27	3.363		0.482		0.08	1.9
Barley (average)	371.55	79.9	9.05	1.75	2.3	30.5	281	6.7	2.77		452	133	12	0	0.295	0.285	3	0.0	0.318	19	0.57	2.2
Wheat (average)	358.9	75.1	10.2	1.9	3.0	41.7	306.7	8.0	3.6		427.0	109.0	12.0	0	0.3	0.1	3.1	0.0	0.364	44.0		
Maize (average)	232.4	63.7	6.2	4.1	2.5	11.0	251.0	3.8	1.8	0.2	284.0	127.0	35.0	0.9	0.2	0.1	3.5	0.0	0.622	19.0	0.5	0.3
Sorghum (average)	369.9	78.9	6.7	3.1	2.4	26.3	306.7	9.4	0.8	0.3	131.0	165.0	7.0	0.0	0.4	0.1	2.2	0.0	0.443	20.0	0.5	
Finger millet (average)	344.0	79.2	6.4	1.5	5.3	392.4	268.7	22.2	1.9	0.9	432.4	114.0	203.2	0.2	0.1	0.1	0.8	0.0	0.4	85.0	0.05	0.9
Oats)	373	57.8	10.7	7.5	15.5	54	491	4.4	3.2		362		12	0	0.76	0.14	0.8	0				
Rice	357.2	81.5	6.9	0.4	0.2	12	132	2.3	1.1	0.1	81	116	0	0	0.1	0.02	2.3	0	0.477	23	0.60	0.6
Faba bean (average)	202.3	36.4	12.4	0.8	8.0	61.0	246.8	3.7	2.3		732.5	192.0	13.5	112.0	0.2	0.2	2.7	1.4	0.4	423.0	0.05	9.0

	COMPOSITION IN TERMS OF 100 GRAMS EDIBLE PORTION																					
	Energy	Carbohydrates (incl. fiber)	Protein	Fat	Fiber	Calcium	Phosphorous	Iron	Zinc	Copper	Potassium	Magnesium	Sodium	-carotene Equiv.	Thiamine	Riboflavin	Niacin	Vitamin C: total ascorbic acid	Vitamin B6	Folate(total)	Vitamin E	Vitamin K
	[kcal 100 g^{-1}]	[g 100 g^{-1}]	[g 100 g^{-1}]	[g 100 g^{-1}]	[g 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[µg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[µg 100 g^{-1}]	[mg 100 g^{-1}]	[µg 100 g^{-1}]
Field pea (average)	193.5	39.5	7.9	0.5	4.8	48.5	199.0	2.9	1.2		244.0	33.0	5.0	0.5	0.2	0.2	1.1	40.0	0.2	65.0	0.13	24.8
Haricot bean (average)	40.0	5.0	3.1	0.2	2.5	47.2	56.0	1.0	0.3	0.1	242.3		2.4	286.2	0.1	0.1	0.7	4.3				
Chickpea (average)	161.6	16.0	6.1	1.0	5.6	89.0	114.3	6.5	1.5	0.4	291.0	48.0	9.0	1.2	0.2	0.1	3.1	1.2				
Lentil (dried)	352.2	63.2	22.6	1	4.8	68	359	28.3	0.5	0.17	303	47			0.37	0.15	1.6	4.5	0.54	479	0.49	5.0
Soybean	386	9.7	34.0	19.1	19.3	228	384	7.3	5.00	1.7	1 798	280	3	5	0.73	0.15	2.59	6	0.377	375	0.85	47
Fenugreek	360	52.9	28.9	7.2	7.9	155.9	218.3	9.7	3.8	1.49	880.5	191	35.8		0.09	0.29		3	0.600	57		
Mung bean	306	54.9	20.3	1.3	17.2	63	412	6.6	3.4	0.7	734		11		0.5	0.2	1.3	2.4				
Gibto	394.3	47.1	32.8	8.3	12.9	213	292	8.6	4.75		1013	198	15	0.2	0.09	0.32	1.8	4.8	0.357	355		
Neug (dried)	519.8	36.5	18.3	33.4	18.3	331	843	72.5						0	0.88	0.43						
Linseed (dried)	510.9	43.9	17.0	29.7	10.3	227		6	4.34		813		30	0	0.35	0.11	2	0.0				
Groundnut (dried)	581.7	26.8	23.0	42.5	3.5	51	252	3	3.3	1.1	705	168	18		0.64	0.135	12.07	0.0	0.348	240	8.33	0
Sunflower (dried)	588	9.4	26.4	54.8	10.1	131	776	7.8	10.3	1.5	407		40		0.7	0.1	4.7	0				

	COMPOSITION IN TERMS OF 100 GRAMS EDIBLE PORTION																					
	Energy	Carbohydrates (incl. fiber)	Protein	Fat	Fiber	Calcium	Phosphorous	Iron	Zinc	Copper	Potassium	Magnesium	Sodium	-carotene Equiv.	Thiamine	Riboflavin	Niacin	Vitamin C: total ascorbic acid	Vitamin B6	Folate(total)	Vitamin E	Vitamin K
	[kcal 100 g^{-1}]	[g 100 g^{-1}]	[g 100 g^{-1}]	[g 100 g^{-1}]	[g 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[µg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[µg 100 g^{-1}]	[mg 100 g^{-1}]	[µg 100 g^{-1}]
Sesame seed (dried)	597	11	22.4	45.8	14	1	411	10.8	7.75	4.1	468	351.00	11	0.32	0.16	0.04	1.8	0.0	0.79	97.00	0.25	0.0
Rapeseed	309.4			35.0								0						0	0	0	0	0
Lettuce	15.4	2.4	1	0.2	0.7	22	31	1.6	0.2	0	158	13	9	0.72	0.08	0.18	0.375	9.2	0.09	38	0.22	126.3
Head cabbage	20.5	4	0.9	0.1	0.9	43	29	0.8	0.2	0	170	12	18	0.04	0.04	0.01	0.234	36.6	0.124	43	0.15	76
Ethiopian cabbage	27	0.2	3.3	0.6	4	117	51	5.7	0.7		639	33	7	1 418	0.06	0.23	0.9	93.4	0.147	62	0.66	389.6
Tomato	30.7	4.8	1.3	0.7	1.5	9	29	0.9	0.1	0.1	222	11	9	620	0.06	0.05	0.5	13.7	0.08	15	0.54	7.9
Green pepper	46.5	8.8	1.7	0.5	3.4	15	38	1.5	0.2	0	131	25	10	500	0.07	0.06	1	242.5	0.278	23	0.69	14.3
Red pepper	93.3	15.7	2	2.5	8.5	19	78	3.7	0.1	0.4	146	23	15	1 720	0.1	0.42	2.3	143.7	0.506	23	0.69	14.0
Swiss chard	27.6	3.8	2.2	0.4	1.1	85	41	3.6	2.8	0.9	379	81	213	3.06	0.11	0.57	0.6	30.0	0.099	14	1.89	830
Beetroot	44	6.9	2.17	0.1	3.31	13	36	0.8	0.55		298	23	60	10	0.01	0.02	0.3	4.9	0.067	109	0.04	0.2
Carrot	42	7.9	1.7	0.4	1	31	33	1.3	0.2	0	320	12	69	4 780	0.04	0.03	0.5	5.9	0.138	19	0.66	13.2
Onion (average)	54.7	11.5	1.6	0.2	0.9	39.4	41.1	1.5	0.2	0.1	303.1	10.0	5.0	0.0	0.0	0.1		7.4	0.1	19.0	0.02	0.40

COMPOSITION IN TERMS OF 100 GRAMS EDIBLE PORTION																						
	Energy	Carbohydrates (incl. fiber)	Protein	Fat	Fiber	Calcium	Phosphorous	Iron	Zinc	Copper	Potassium	Magnesium	Sodium	-carotene Equiv.	Thiamine	Riboflavin	Niacin	Vitamin C: total ascorbic acid	Vitamin B6	Folate(total)	Vitamin E	Vitamin K
	[kcal 100 g^{-1}]	[g 100 g^{-1}]	[g 100 g^{-1}]	[g 100 g^{-1}]	[g 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[µg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[mg 100 g^{-1}]	[µg 100 g^{-1}]	[mg 100 g^{-1}]	[µg 100 g^{-1}]
Potato (average)	86.4	19.9	0.9	0.8	1.1	21.5	73.5	5.8	0.4	0.4	413.0	23.0	10.0	0.0	0.1	0.1	0.9	19.7	0.298	15.0	0.0	2.0
Yam	98.1	21.2	3.1	0.1	1.7	119	13.3	1.8	0.5	0.17	303	21	3					17.1	0.293	23	0.35	2.3
Garlic	138.3	29.8	4.1	0.3	1.1	36	133	2.1	1.16		401	25	17	0	0.21	0.07	0.3	31.2	1.235	3	0.08	1.7
Taro	124.2	28.4	2.2	0.2	1	29	42	2	0.2	0.2	591	33	11	0	0.12	0.06	0.5	4.5	0.283	22	2.38	1
Sweet potato	136	28.2	1.3	2	1.1	52	34	3.4	0.3	0.2	251	25	7	0	0.08	0.05	0.9	2.4	0.209	11	0.29	1.8
Avocado	110.1	5	1.6	9.3	3.1	13	40	1.7	0.6	0.2	599	24	7	0	0.06	0.11	0.8	17.4	0.078	35	2.66	
Banana	87.8	25.4	0.8	0.33	2.6	8	30	0.5	0.2	0.1	358	27	1	3	0.04	0.1	1	8.7	0.367	20	0.1	0.5
Guava	43.1	13.5	0.9	1.0	8.8	22.0	25.0	1.7	0.2	0.5	220.0	22.0	6.6	960.0	0.0	0.1	9.0	228.3	0.1	49.0	0.73	2.6
Lemon	41.0	9.2	0.5	0.5	1.3	29.6	19.1	0.9	0.08	0.12	7.40	8.0	145.9	0.0	0.0	0.0	0.4	53.0	0.1	11.0	0.15	0.0
Mango	43.8	14.98	0.82	0.38	1.2	20	9	0.6	0	0.1	156	10	2	0	0.03	0.02		36.4	0.119	43	0.9	4.2
Orange	33.9	5.3	0.7	1.1	1.4	50	23	0.8	0.1	0.1	181	14	0	335	0.08	0.05	0.6	71	0.093	30		
Papaya	34.9	7.8	0.7	0.1	0.8	15	13	0.5	0.1	0	257	21	3	0.04	0.01	0.09		60.9	0.038	37	0.3	2.6
Pineapple	35.3	8.2	0.4	0.1	0.9	34	15	0.09	0.1	0.1	113	12	1	0	0.04	0.05		47.8	0.112	18	0.02	0.7

TABLE 5

Average yield (year 2015-2018), energy content, sum of macro and micronutrients for main crops produced in Ethiopia. Values are calculated with data from Ethiopia Central Statistical Agency, 2007; EPHI, 2013; Baye, 2014; Lukmanju, and Hertzmark, 2008; FAO/Government of Kenya 2018; FAO, 2012; USDA (undated). The headline 'Missing values' specifies where values have not been included for the specified crop in either food composition table

Crop	Yield	Sum macronutrients	Sum micronutrients	Sum minerals (Ca, P, Fe, Zn, K, Mg)	Sum vitamins (-carotene eqv, B1, B2, B3, B6, C, E, K, Folate)	Missing values
	[ton ha^{-1}]	[g 100g^{-1}]	[mg 100g^{-1}]	[mg 100g^{-1}]	[mg 100g^{-1}]	
Teff (average)	1.7	92.0	1 235.8	1 231.3	4.59	Vitamin C
Barley (average)	2.1	90.7	910.5	906.0	4.49	Copper
Wheat (average)	2.6	87.2	900.0	896.0	3.96	Copper, Vitamin E, Vitamin K
Maize (average)	3.7	74.0	683.5	678.6	4.90	
Sorghum (average)	2.5	88.6	642.9	639.2	3.69	Vitamin K
Finger millet (average)	2.2	87.0	1 233.1	1 231.6	1.45	
Oats	2.0	76.0	916.3	914.6	1.70	Copper, Folate, Vitamin B6, Vitamin E, Vitamin K
Rice	2.8	88.8	347.9	344.4	3.52	
Faba bean (average)	2.0	49.6	1 243.7	1 238.2	5.43	Copper
Field pea (average)	1.6	47.8	570.5	528.6	41.90	Copper
Haricot bean (average)	1.6	8.4	351.9	346.7	5.20	Magnesium, Folatem Vitamin B6, Vitamin E, Vitamin K
Chickpea (average)	2.0	23.1	554.8	550.2	4.61	Folate, Vitamin B6, Vitamin E, Vitamin K
Lentil (dried)	1.4	86.8	813.9	805.8	8.13	ß-carotene
Soybean	2.2	62.8	2 713.4	2 702.3	11.12	
Fenugreek	1.3	89.0	1 463.2	1 459.2	4.04	ß-carotene, Vitamin E, Vitamin K
Mung bean	1.1	76.5	1 223.4	1 219.0	4.40	Magnesium, ß-carotene, Folate, Vitamin B6, Vitamin E, Vitamin K
Gibto	1.3	88.2	1 737.1	1 729.4	7.72	Copper, Vitamin E, Vitamin K

Crop	Yield	Sum macronutrients	Sum micronutrients	Sum minerals (Ca, P, Fe, Zn, K, Mg)	Sum vitamins (-carotene eqv, B1, B2, B3, B6, C, E, K, Folate)	Missing values
	[ton ha^{-1}]	[g 100g^{-1}]	[mg 100g^{-1}]	[mg 100g^{-1}]	[mg 100g^{-1}]	
Neug (dried)	1.0	88.2	1 247.8	1 246.5	1.31	Zinc, Copper, Potassium, magnesium, Folate, Vitamin C, Vitamin B6, Vitamin E, Vitamin K
Linseed (dried)	1.1	90.6	1 052.8	1 050.3	2.46	Phosphorus, Copper, Magnesium, Folate, Vitamin B8, Vitamin E, Vitamin K
Groundnut (dried)	1.7	92.3	1 204.1	1 182.3	21.76	
Sunflower (dried)	1.1	90.6	1 337.6	1 332.1	5.50	Magnesium, b-carotene, Folate, Vitamin B6, Vitamin E, Vitamin K
Sesame seed (dried)	0.7	79.2	1 252.7	1 249.6	3.14	
Rapeseed	1.8	35.0	0.0	0.0	0.00	
Lettuce	0.7	3.6	236.1	225.8	10.31	
Head cabbage	6.3	5.0	292.3	255.0	37.28	
Ethiopian cabbage	9.9	4.1	942.2	846.4	95.85	Copper
Tomato	5.3	6.8	287.0	272.0	14.95	
Green pepper	6.2	11.0	455.3	210.7	244.64	
Red pepper	1.8	20.2	417.6	269.8	147.75	
Swiss chard	2.5	6.4	626.5	592.4	34.11	
Beetroot	8.9	9.2	376.8	371.4	5.45	Copper
Carrot	3.8	10.0	404.8	397.5	7.30	
Onion (average)	9.3	13.2	402.9	395.2	7.65	
Potato (average)	13.7	21.5	558.2	537.2	21.01	
Yam	9.2	24.4	476.4	458.6	17.77	
Garlic	9.1	34.2	631.4	598.3	33.10	
Taro	25.3	30.8	705.1	697.2	7.87	
Sweet potato	34.6	31.5	369.6	365.7	3.94	
Avocado	4.0	15.9	699.4	678.3	21.14	

Crop	Yield	Sum macronutrients	Sum micronutrients	Sum minerals (Ca, P, Fe, Zn, K, Mg)	Sum vitamins (-carotene eqv, B1, B2, B3, B6, C, E, K, Folate)	Missing values
	[ton ha^{-1}]	[g 100g^{-1}]	[mg 100g^{-1}]	[mg 100g^{-1}]	[mg 100g^{-1}]	
Banana	8.3	26.6	434.0	423.7	10.33	
Guava (average)	1.2	15.4	529.2	290.9	238.28	
Lemon (average)	5.6	10.1	118.8	65.0	53.71	
Mango	7.6	16.2	233.1	195.6	37.52	
Orange	12.7	7.1	340.8	268.9	71.85	
Papaya	8.3	8.6	368.0	306.6	61.38	
Pineapple	1.2	8.7	222.2	174.2	48.04	

APPENDIX B

TABLE 6
Minimum and maximum nutritional water productivity (NWP) values calculated for main crops in Ethiopia: macronutrients and minerals

		Nutritional Water Productivity												
Crop	Water productivity	Energy	Carbohydrates (incl. fiber)	Protein	Fat	Fiber	Calcium	Potassium	Phosphorous	Iron	Zinc	Copper	Sodium	Magnesium
		[kcal m^{-3}]	[g m^{-3}]				[mg m^{-3}]						[mg m^{-3}]	mg m^{-3}
Barley	Min ETc	7 720.8	1 660.3	188.1	36.4	47.8	633.8	9392.6	5 839.2	139.2	57.6		249.4	2763.7
	Max ETc	1 187.8	255.4	28.9	5.6	7.4	97.5	1 445.0	898.3	21.4	8.9		38.4	425.2
Barley (rainfed)		1 523.4	327.6	37.1	7.2	9.4	125.1	1 853.2	1 152.1	27.5	11.4	0.0	49.2	545.3
Wheat	Min ETc	4 753.5	995.0	135.5	24.7	39.7	551.8	5654.9	4 061.3	106.4	48.1		158.9	1443.5
	Max ETc	1 462.6	306.2	41.7	7.6	12.2	169.8	1 740.0	1 249.6	32.7	14.8		48.9	444.2
Wheat (rainfed)	Min	753.8	157.8	21.5	3.9	6.3	87.5	896.7	644.0	16.9	7.6	0.0	25.2	228.9
	Median	789.7	165.3	22.5	4.1	6.6	91.7	939.4	674.7	17.7	8.0	0.0	26.4	239.8
	Max	825.5	172.8	23.5	4.3	6.9	95.8	982.1	705.3	18.5	8.3	0.0	27.6	250.7
Wheat (irrigated)	Min	1 148.6	240.4	32.7	6.0	9.6	133.3	1 366.4	981.3	25.7	11.6	0.0	38.4	348.8
	Median	2 727.9	571.0	77.8	14.2	22.8	316.7	3 245.2	2 330.7	61.1	27.6	0.0	91.2	828.4
	Max	3 876.5	811.4	110.5	20.2	32.4	450.0	4 611.6	3 312.0	86.8	39.2	0.0	129.6	1177.2
Durum wheat (irrigated)	Min	1 722.9	360.6	49.1	9.0	14.4	200.0	2 049.6	1 472.0	38.6	17.4	0.0	57.6	523.2
	Median	2 010.0	420.7	57.3	10.5	16.8	233.3	2 391.2	1 717.3	45.0	20.3	0.0	67.2	610.4
	Max	2 369.0	495.9	67.5	12.3	19.8	275.0	2 818.2	2 024.0	53.0	24.0	0.0	79.2	719.4

		Nutritional Water Productivity												
Crop	**Water productivity**	**Energy**	**Carbohydrates (incl. fiber)**	**Protein**	**Fat**	**Fiber**	**Calcium**	**Potassium**	**Phosphorous**	**Iron**	**Zinc**	**Copper**	**Sodium**	**Magnesium**
		[kcal m^{-3}]	[g m^{-3}]				[mg m^{-3}]						[mg m^{-3}]	mg m^{-3}
Maize	Min ETc	2 131.5	583.9	57.2	37.3	22.6	100.9	2 604.8	2 302.1	35.2	16.5	1.8	321.0	1164.8
	Max ETc	1 065.7	292.0	28.6	18.6	11.3	50.4	1 302.4	1 151.0	17.6	8.3	0.9	160.5	582.4
Maize (rainfed)	Min	836.6	229.2	22.4	14.6	8.9	39.6	1 022.4	903.6	13.8	6.5	0.7	126.0	457.2
Maize (irrigate) d	Min	945.1	258.9	25.3	16.5	10.0	44.7	1 154.9	1 020.7	15.6	7.3	0.8	142.3	516.5
	Median	3 323.3	910.4	89.1	58.2	35.3	157.3	4 061.2	3 589.3	54.8	25.7	2.9	500.5	1816.1
	Max	3 997.3	1 095.1	107.2	69.9	42.4	189.2	4 884.8	4 317.2	65.9	31.0	3.4	602.0	2184.4
Sorghum	Min ETc	3 115.9	664.4	56.4	25.8	20.5	221.8	1 103.6	2 583.5	79.5	6.7	2.5	59.0	1390.0
	Max ETc	1 246.4	265.8	22.6	10.3	8.2	88.7	441.4	1 033.4	31.8	2.7	1.0	23.6	556.0
Sorghum (rainfed)	Min	887.7	189.3	16.1	7.4	5.8	63.2	314.4	736.0	22.6	1.9	0.7	16.8	396.0
Sorghum (irrigated)	Min	1 215.8	259.3	22.0	10.1	8.0	86.6	430.6	1 008.1	31.0	2.6	1.0	23.0	542.4
Finger millet	Min ETc	1 658.7	381.8	30.9	7.0	25.8	1 892.0	2 085.1	1 295.8	107.1	9.2	4.3	980.0	549.7
	Max ETc	1 148.4	264.3	21.4	4.9	17.8	1 309.9	1 443.6	897.1	74.2	6.4	3.0	678.5	380.6
Millet (rainfed)	Min	1 307.1	300.9	24.3	5.5	20.3	1 491.0	1 643.1	1 021.1	84.4	7.3	3.4	772.3	433.2
Rice	Min ETc	2 234.0	509.7	43.2	2.5	1.3	75.0	506.6	825.5	14.4	6.9	0.6		725.5
	Max ETc	913.9	208.5	17.7	1.0	0.5	30.7	207.2	337.7	5.9	2.8	0.3		296.8
Rice (irrigated)	Min	2 393.2	546.1	46.2	2.7	1.3	80.4	542.7	884.4	15.4	7.4	0.7	0.0	777.2

		Nutritional Water Productivity												
Crop	Water productivity	Energy	Carbohydrates (incl. fiber)	Protein	Fat	Fiber	Calcium	Potassium	Phosphorous	Iron	Zinc	Copper	Sodium	Magnesium
		[kcal m^{-3}]	[g m^{-3}]				[mg m^{-3}]						[mg m^{-3}]	mg m^{-3}
Teff	Min ETc	1 314.8	294.6	35.0	9.2	11.0	662.9	1 572.6	1 580.0	28.1	13.4	5.9	44.2	677.7
	Max ETc	1 075.8	241.1	28.6	7.5	9.0	542.4	1 286.7	1 292.7	23.0	10.9	4.8	36.2	554.5
Teff (rainfed)	Min	856.8	192.0	22.8	6.0	7.2	432.0	1 024.8	1 029.6	18.3	8.7	3.8	28.8	441.6
	Median	1 017.5	228.0	27.1	7.1	8.6	513.0	1 217.0	1 222.7	21.7	10.3	4.6	34.2	524.4
	Max	1 178.1	264.0	31.4	8.3	9.9	594.0	1 409.1	1 415.7	25.2	12.0	5.3	39.6	607.2
Teff (irrigated)	Min	820.7	183.9	21.8	5.7	6.9	413.8	981.6	986.2	17.5	8.3	3.7	27.6	423.0
	Median	3 320.1	744.0	88.4	23.3	27.9	1 674.0	3 971.1	3 989.7	71.0	33.8	14.9	111.6	1711.2
	Max	5 319.3	1 192.0	141.6	37.3	44.7	2 682.0	6 362.3	6 392.1	113.7	54.1	23.8	178.8	2741.6
Oats	Min ETc	1 630.1	252.6	46.8	32.8	67.7	236.0	1 582.1	2 145.9	19.2	14.0		52.4	
	Max ETc	1 128.6	174.9	32.4	22.7	46.9	163.4	1 095.3	1 485.6	13.3	9.7		36.3	
Potato	Min ETc	3 383.1	777.7	35.3	29.4	41.1	842.3	16 180.9	2 879.7	227.2	15.7	15.7	391.8	901.1
	Max ETc	1 691.6	388.9	17.6	14.7	20.6	421.2	8 090.5	1 439.8	113.6	7.8	7.8	195.9	450.6
Potato (rainfed)	Min	2 046.5	470.4	21.3	17.8	24.9	509.6	9 788.1	1 742.0	137.5	9.5	9.5	237.0	545.1
	Median	2 111.3	485.3	22.0	18.3	25.7	525.7	10 097.9	1 797.1	141.8	9.8	9.8	244.5	562.4
	Max	2 176.0	500.2	22.7	18.9	26.5	541.8	10 407.6	1 852.2	146.2	10.1	10.1	252.0	579.6
Potato (irrigated)	Min	961.8	201.5	13.1	2.6	15.0	311.8	5 334.6	722.5	25.5	3.9	1.1	88.0	176.0
	Median	2499.8	574.7	40.1	21.7	31.3	963.3	12 307.4	2 127.8	167.9	11.6	11.6	289.5	665.9

		Nutritional Water Productivity												
Crop	Water productivity	Energy	Carbohydrates (incl. fiber)	Protein	Fat	Fiber	Calcium	Potassium	Phosphorous	Iron	Zinc	Copper	Sodium	Magnesium
		[kcal m^{-3}]	[g m^{-3}]				[mg m^{-3}]						[mg m^{-3}]	mg m^{-3}
	Max	17 160.3	3 944.8	178.9	149.0	208.7	4 272.7	82 075.5	14 606.7	1 152.6	79.5	79.5	1 987.3	4570.8
Onion	Min ETc	1 457.2	305.3	43.5	4.0	22.7	1 050.6	8081.8	1 094.5	38.7	5.9	1.6	133.3	266.6
	Max ETc	850.0	178.1	25.4	2.3	13.2	612.8	4 714.4	638.5	22.6	3.4	0.9	77.8	155.5
Onion (rainfed)	Min	1 043.8	218.7	31.1	2.9	16.2	752.5	5 789.2	784.1	27.7	4.2	1.1	95.5	191.0
Onion (irrigated)	Min	756.9	158.6	22.6	2.1	11.8	545.7	4 197.9	568.5	20.1	3.0	0.8	69.3	138.5
	Median	3 683.4	771.7	109.9	10.1	57.3	2 655.6	20 428.9	2 766.8	97.7	14.8	4.0	337.0	674.0
	Max	5 563.4	1 165.6	165.9	15.3	86.5	4 010.9	30 855.6	4 178.9	147.6	22.4	6.1	509.0	1018.0
Sweet potato	Min ETc	11 779.0	2 442.4	112.6	173.2	95.3	4 503.7	21 739.1	2 944.7	294.5	26.0	17.3	606.3	2165.3
	Max ETc	7 538.5	1 563.1	72.1	110.9	61.0	2 882.4	13 913.0	1 884.6	188.5	16.6	11.1	388.0	1385.8
Garlic (irrigated)	Min	1 590.5	342.7	47.2	3.5	12.7	414.0	4 611.5	1 529.5	24.2	13.3	0.0	195.5	287.5
Pulses (rainfed)	Min	364.1	65.6	22.2	1.4	14.4	109.8	1 318.5	444.2	6.6	4.1	0.0	24.3	345.6
	Median	869.9	156.6	53.1	3.4	34.5	262.3	3 149.8	1 061.0	15.8	9.9	0.0	58.1	825.6
	Max	1 375.6	247.7	84.0	5.4	54.6	414.8	4 981.0	1 677.9	25.0	15.7	0.0	91.8	1305.6
Faba bean	Min ETc	1 638.4	295.0	100.0	6.5	65.0	494.0	5 932.3	1 998.3	29.8	18.7		109.3	1554.9
	Max ETc	819.2	147.5	50.0	3.2	32.5	247.0	2 966.1	999.2	14.9	9.3		54.7	777.5
Field pea	Min ETc	878.8	179.3	35.8	2.0	21.8	220.3		904.0	13.2				149.9
	Max ETc	615.2	125.5	25.0	1.4	15.3	154.2		632.8	9.2				104.9

		Nutritional Water Productivity												
Crop	Water productivity	Energy	Carbohydrates (incl. fiber)	Protein	Fat	Fiber	Calcium	Potassium	Phosphorous	Iron	Zinc	Copper	Sodium	Magnesium
		[kcal m^{-3}]	[g m^{-3}]				[mg m^{-3}]						[mg m^{-3}]	mg m^{-3}
Soybean	Min ETc	2 838.0	71.3	250.0	140.4	141.9	1 676.3	13 219.3	2 823.3	53.7	36.8	12.5	22.1	2058.6
	Max ETc	1 032.0	25.9	90.9	51.1	51.6	609.6	4 807.0	1 026.6	19.5	13.4	4.5	8.0	748.6
Chickpea (irrigated)	Min	333.2	33.0	12.5	2.1	11.6	183.5	600.0	235.6	13.4	3.1	0.8	0.0	99.0
Sesame seed (irrigated)	Min	5 934.2	109.3	222.7	455.3	139.2	9.9	4 651.9	4 085.3	107.4	77.0	40.8	109.3	3488.9
	Median	6 961.0	128.3	261.2	534.0	163.2	11.7	5 456.9	4 792.3	125.9	90.4	47.8	128.3	4092.7
	Max	9 874.4	181.9	370.5	757.5	231.6	16.5	7 740.7	6 797.9	178.6	128.2	67.8	181.9	5805.5
Sunflower (dried)	Min ETc	1 435.6	22.9	64.5	133.8	24.7	319.8	993.7	1 894.6	19.0	25.1	3.7	97.7	
	Max ETc	64.6	1.0	2.9	6.0	1.1	14.4	44.7	85.3	0.9	1.1	0.2	4.4	
Rapeseed	Min ETc	1 888.7			213.7									0.0
	Max ETc	944.4			106.8									0.0
Groundnuts (dried)	Min ETc	1 969.2	90.7	77.9	143.9	11.8	172.7	2 386.7	853.1	10.2	11.2	3.7	0.0	568.7
	Max ETc	1 406.6	64.8	55.6	102.8	8.5	123.3	1 704.8	609.4	7.3	8.0	2.7		406.2
Green pepper	Min ETc	481.4	91.1	17.6	5.2	35.2	155.3	1 356.3	393.4	15.5	2.1		103.5	258.8
	Max ETc	321.0	60.7	11.7	3.5	23.5	103.5	904.2	262.3	10.4	1.4	0.0	69.0	172.6
Green pepper (rainfed)	Min	233.4	44.2	8.5	2.5	17.1	75.3	657.6	190.8	7.5	1.0	0.0	50.2	125.5
	Median	857.9	162.4	31.4	9.2	62.7	276.8	2 417.0	701.1	27.7	3.7	0.0	184.5	461.3

		Nutritional Water Productivity												
Crop	Water productivity	Energy	Carbohydrates (incl. fiber)	Protein	Fat	Fiber	Calcium	Potassium	Phosphorous	Iron	Zinc	Copper	Sodium	Magnesium
		[kcal m^{-3}]	[g m^{-3}]				[mg m^{-3}]						[mg m^{-3}]	mg m^{-3}
	Max	1 841.4	348.5	67.3	19.8	134.6	594.0	5 187.6	1 504.8	59.4	7.9	0.0	396.0	990.0
Red pepper	Min ETc	279.8	47.1	6.0	7.5	25.5	57.0	437.8	233.9	11.1	0.3	1.2	45.0	69.0
	Max ETc	186.5	31.4	4.0	5.0	17.0	38.0	291.9	155.9	7.4	0.2	0.8	30.0	46.0
Head cabbage	Min ETc	366.3	71.5	16.1	1.8	16.1	768.4	3 037.8	518.2	14.3	3.6		321.7	214.4
	Max ETc	256.4	50.0	11.3	1.3	11.3	537.9	2 126.5	362.8	10.0	2.5		225.2	150.1
Tomato	Min ETc	546.4	85.4	23.1	12.5	26.7	160.2	3 951.4	516.2	16.0	1.8	1.8	160.2	195.8
	Max ETc	204.9	32.0	8.7	4.7	10.0	60.1	1 481.8	193.6	6.0	0.7	0.7	60.1	73.4
Banana	Min ETc	916.0	265.4	8.3	3.4	27.1	83.5	3 734.8	313.0	5.2	2.1	1.0	10.4	281.7
	Max ETc	732.8	212.3	6.7	2.8	21.7	66.8	2 987.9	250.4	4.2	1.7	0.8	8.3	225.3
Lemon	Min ETc	257.4	57.7	2.9	2.9	7.9	185.9	46.4	119.6	5.4	0.5	0.8	915.3	50.2
	Max ETc	193.1	43.3	2.2	2.2	6.0	139.4	34.8	89.7	4.1	0.4	0.6	686.5	37.6

TABLE 7
Minimum and maximum nutritional water productivity values calculated for crops produced in Ethiopia: vitamins

		Nutritional Water Productivity (NWP)								
Crop	**Water productivity**	**ß-carotene Equiv.**	**Thiamine**	**Riboflavin**	**Niacin**	**Vitamin C: total ascorbic acid**	**Vitamin B6**	**Folate (total)**	**Vitamin E (alphatocopherol)**	**Vitamin K (phylloquinone)**
		[µg m^{-3}]	mg m^{-3}	mg m^{-3}	mg m^{-3}	mg m^{-3}	mg m^{-3}	µg m^{-3}	mg m^{-3}	µg m^{-3}
Barley	**Min ETc**	0.0	6.1	5.9	62.3	0.0	6.6	394.8	11.8	45.7
	Max ETc	0.0	0.9	0.9	9.6	0.0	1.0	60.7	1.8	7.0
Barley (rainfed)		0.0	1.2	0.0	12.3	0.0	1.3	77.9	2.3	9.0
Wheat	**Min Etc**	0.0	3.9	1.6	41.5	0.0	4.8	582.7	0.0	0.0
	Max Etc	0.0	1.2	0.5	12.8	0.0	1.5	179.3	0.0	0.0
Wheat (rainfed)	Min	0.0	0.6	0.3	6.6	0.0	0.8	92.4	0.0	0.0
	Median	0.0	0.7	0.3	6.9	0.0	0.8	96.8	0.0	0.0
	Max	0.0	0.7	0.3	7.2	0.0	0.8	101.2	0.0	0.0
Wheat (irrigated)	Min	0.0	0.9	0.4	10.0	0.0	1.2	140.8	0.0	0.0
	Median	0.0	2.3	0.9	23.8	0.0	2.8	334.4	0.0	0.0
	Max	0.0	3.2	1.3	33.8	0.0	3.9	475.2	0.0	0.0
Durum wheat (irrigated)	Min	0.0	1.4	0.6	15.0	0.0	1.7	211.2	0.0	0.0
	Median	0.0	1.7	0.7	17.5	0.0	2.0	246.4	0.0	0.0
	Max	0.0	2.0	0.8	20.7	0.0	2.4	290.4	0.0	0.0
Maize	**Min ETc**	8.1	1.7	1.0	31.8	0.0	5.7	174.3	4.5	2.8
	Max ETc	4.0	0.9	0.5	15.9	0.0	2.9	87.1	2.2	1.4

		Nutritional Water Productivity (NWP)								
Crop	**Water productivity**	**ß-carotene Equiv.**	**Thiamine**	**Riboflavin**	**Niacin**	**Vitamin C: total ascorbic acid**	**Vitamin B6**	**Folate (total)**	**Vitamin E (alphatocopherol)**	**Vitamin K (phylloquinone)**
		[µg m^{-3}]	mg m^{-3}	mg m^{-3}	mg m^{-3}	mg m^{-3}	mg m^{-3}	µg m^{-3}	mg m^{-3}	µg m^{-3}
Maize (rainfed)	Min	3.2	0.7	0.4	12.5	0.0	2.2	68.4	1.8	1.1
Maize (irrigated)	Min	3.6	0.8	0.5	14.1	0.0	2.5	77.3	2.0	1.2
	Median	12.6	2.7	1.6	49.6	0.0	8.9	271.7	7.0	4.3
	Max	15.1	3.3	1.9	59.6	0.0	10.7	326.8	8.4	5.2
Sorghum	**Min ETc**	0.0	3.1	1.0	18.8	0.0	3.7	168.5	4.2	0.0
	Max ETc	0.0	1.3	0.4	7.5	0.0	1.5	67.4	1.7	0.0
Sorghum (rainfed)	Min	0.0	0.9	0.3	5.4	0.0	1.1	48.0	1.2	0.0
Sorghum (irrigated)	Min	0.0	1.2	0.4	7.3	0.0	1.5	65.7	1.6	0.0
Finger millet	**Min ETc**	0.7	0.3	0.5	3.6	0.0	1.9	409.9	0.2	4.3
	Max ETc	0.5	0.2	0.4	2.5	0.0	1.3	283.8	0.2	3.0
Millet (rainfed)	Min	0.6	0.3	0.4	2.9	0.0	1.5	323.0	0.2	3.4
Rice	**Min ETc**	0.0	0.6	0.1	14.4	0.0	3.0	143.8	3.8	3.8
	Max ETc	0.0	0.3	0.1	5.9	0.0	1.2	58.8	1.5	1.5
Rice (irrigated)	Min	0.0	0.7	0.1	15.4	0.0	3.2	154.1	4.0	4.0
Teff	**Min ETc**	0.0	1.4	1.0	12.4	0.0	1.8	0.0	0.3	7.0
	Max ETc	0.0	1.2	0.8	10.1	0.0	1.5	0.0	0.2	5.7
Teff (rainfed)	Min	0.0	0.9	0.6	8.1	0.0	1.2	0.0	0.2	4.6

		Nutritional Water Productivity (NWP)								
Crop	**Water productivity**	**ß-carotene Equiv.**	**Thiamine**	**Riboflavin**	**Niacin**	**Vitamin C: total ascorbic acid**	**Vitamin B6**	**Folate (total)**	**Vitamin E (alphatocopherol)**	**Vitamin K (phylloquinone)**
		[μg m^{-3}]	**mg m^{-3}**	**mg m^{-3}**	**mg m^{-3}**	**mg m^{-3}**	**mg m^{-3}**	**μg m^{-3}**	**mg m^{-3}**	**μg m^{-3}**
	Median	0.0	1.1	0.8	9.6	0.0	1.4	0.0	0.2	5.4
	Max	0.0	1.3	0.9	11.1	0.0	1.6	0.0	0.3	6.3
Teff (irrigated)	Min	0.0	0.9	0.6	7.7	0.0	1.1	0.0	0.2	4.4
	Median	0.0	3.6	2.5	31.3	0.0	4.5	0.0	0.7	17.7
	Max	0.0	5.8	4.0	50.1	0.0	7.2	0.0	1.2	28.3
Oats	**Min ETc**	0.0	3.3	0.6	3.5					
	Max ETc	0.0	2.3	0.4	2.4					
Potato	**Min ETc**	0.0	2.9	2.4	33.3	771.8	11.7	587.7	0.4	78.4
	Max ETc	0.0	1.5	1.2	16.7	385.9	5.8	293.8	0.2	39.2
Potato (rainfed)	Min	0.0	1.8	1.4	20.1	466.9	7.1	355.5	0.2	47.4
	Median	0.0	1.8	1.5	20.8	481.7	7.3	366.8	0.2	48.9
	Max	0.0	1.9	1.5	21.4	496.4	7.5	378.0	0.3	50.4
Potato (irrigated)	Min	0.0	0.7	0.9	0.0	130.2	2.1	217.5	0.1	7.0
	Median	0.0	2.2	1.8	24.6	570.3	8.6	553.3	0.5	57.9
	Max	0.0	14.9	11.9	168.9	3 915.0	59.2	2 981.0	2.0	397.5
Onion	**Min ETc**	0.0	1.1	1.3		197.3	3.2	506.6	0.5	10.7
	Max ETc	0.0	0.6	0.8		115.1	1.9	295.5	0.3	6.2

		Nutritional Water Productivity (NWP)								
Crop	Water productivity	ß-carotene Equiv.	Thiamine	Riboflavin	Niacin	Vitamin C: total ascorbic acid	Vitamin B6	Folate (total)	Vitamin E (alphatocopherol)	Vitamin K (phylloquinone)
		[µg m^{-3}]	mg m^{-3}	mg m^{-3}	mg m^{-3}	mg m^{-3}	mg m^{-3}	µg m^{-3}	mg m^{-3}	µg m^{-3}
Onion (rainfed)	Min	0.0	0.8	1.0	0.0	141.3	2.3	362.9	0.4	7.6
Onion (irrigated)	Min	0.0	0.6	0.7	0.0	102.5	1.7	263.2	0.3	5.5
	Median	0.0	2.7	3.4	0.0	498.8	8.1	1 280.6	1.3	27.0
	Max	0.0	4.1	5.1	0.0	753.3	12.2	1 934.2	2.0	40.7
Sweet potato	**Min ETc**	0.0	6.9	4.3	77.9	207.9	18.1	952.7	25.1	155.9
	Max ETc	0.0	4.4	2.8	49.9	133.0	11.6	609.7	16.1	99.8
Garlic (irrigated)	Min	0.0	2.4	0.8	3.5	358.8	14.2	34.5	0.9	19.6
Pulses (rainfed)	Min	201.6	0.4	0.4	4.9	2.5	0.7	761.4	0.1	16.2
	Median	481.6	1.0	1.1	11.6	6.0	1.6	1 818.9	0.2	38.7
	Max	761.6	1.6	1.7	18.4	9.5	2.5	2 876.4	0.3	61.2
Faba bean	**Min ETc**	907.1	1.9	2.0	21.9	11.3	3.0	3 425.7	0.4	72.9
	Max ETc	453.5	1.0	1.0	10.9	5.7	1.5	1 712.9	0.2	36.4
Field pea	**Min ETc**	2.2	1.1	0.7	5.0	181.7	0.8	295.3	0.6	112.7
	Max ETc	1.6	0.8	0.5	3.5	127.2	0.5	206.7	0.4	78.9
Soybeans	**Min ETc**	36.8	5.4	1.1	19.0	44.1	2.8	2 757.1	6.2	345.6
	Max ETc	13.4	2.0	0.4	6.9	16.0	1.0	1 002.6	2.3	125.7
Chickpea (irrigated)	Min	2.5	0.4	0.3	6.3	2.5	0.0	0.0	0.0	0.0

		Nutritional Water Productivity (NWP)								
Crop	**Water productivity**	**ß-carotene Equiv.**	**Thiamine**	**Riboflavin**	**Niacin**	**Vitamin C: total ascorbic acid**	**Vitamin B6**	**Folate (total)**	**Vitamin E (alphatocopherol)**	**Vitamin K (phylloquinone)**
		[μg m^{-3}]	**mg m^{-3}**	**mg m^{-3}**	**mg m^{-3}**	**mg m^{-3}**	**mg m^{-3}**	**μg m^{-3}**	**mg m^{-3}**	**μg m^{-3}**
Sesame seed (irrigated)	Min	3.2	1.6	0.4	17.9	0.0	7.9	964.2	2.5	0.0
	Median	3.7	1.9	0.5	21.0	0.0	9.2	1 131.0	2.9	0.0
	Max	5.3	2.6	0.7	29.8	0.0	13.1	1 604.4	4.1	0.0
Sunflower (dried)	**Min ETc**	0.0	1.7	0.2	11.5					
	Max ETc	0.0	0.1	0.0	0.5					
Rapeseed	**Min ETc**		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Max ETc		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Groundnut (dried)	**Min ETc**	0.0	2.2	0.5	40.8	0.0	1.2	812.5	0.0	0.0
	Max ETc	0.0	1.5	0.3	29.2	0.0	0.8	580.3	0.0	0.0
Green pepper	**Min ETc**	5 176.7	0.7	0.6	10.4	2510.7	2.9	238.1	7.1	148.1
	Max ETc	3 451.1	0.5	0.4	6.9	1 673.8	1.9	158.8	4.8	98.7
Green pepper (rainfed)	Min	2 510.0	0.4	0.3	5.0	1 217.4	1.4	115.5	3.5	71.8
	Median	9 225.0	1.3	1.1	18.5	4 474.1	5.1	424.4	12.7	263.8
	Max	19 800.0	2.8	2.4	39.6	9 603.0	11.0	910.8	27.3	566.3
Red pepper	**Min ETc**	5 158.1	0.3	1.3	6.9	430.9	1.5	69.0	2.1	42.0
	Max ETc	3 438.7	0.2	0.8	4.6	287.3	1.0	46.0	1.4	28.0

Crop	Water productivity	Nutritional Water Productivity (NWP)								
		ß-carotene Equiv.	Thiamine	Riboflavin	Niacin	Vitamin C: total ascorbic acid	Vitamin B6	Folate (total)	Vitamin E (alphatocopherol)	Vitamin K (phylloquinone)
		[μg m^{-3}]	mg m^{-3}	mg m^{-3}	mg m^{-3}	mg m^{-3}	mg m^{-3}	μg m^{-3}	mg m^{-3}	μg m^{-3}
Head cabbage	**Min ETc**	0.7	0.7	0.2		654.0	2.2	768.4	2.7	1 358.1
	Max ETc	0.5	0.5	0.1		457.8	1.6	537.9	1.9	950.7
Tomato	**Min ETc**	11 035.3	1.1	0.9	8.9	243.8	1.4	267.0	9.6	140.6
	Max ETc	4 138.2	0.4	0.3	3.3	91.4	0.5	100.1	3.6	52.7
Banana	**Min ETc**	31.3	0.4	1.0	10.4	90.8	3.8	208.7	1.0	5.2
	Max ETc	25.0	0.3	0.8	8.3	72.6	3.1	166.9	0.8	4.2
Lemon	**Min ETc**	0.0	0.2	0.2	2.5	332.5	0.5	69.0	0.9	0.0
	Max ETc	0.0	0.2	0.2	1.9	249.4	0.4	51.8	0.7	0.0

Ar	–	*Arabic*	*Multil*	*+ Multilingual*
C	–	*Chinese*	*	*Out of print*
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LAND AND WATER DISCUSSION PAPER

Water productivity, the yield gap, and nutrition

The case of Ethiopia

Today, the implementation of the Sustainable Development Goals on food and water security is uncertain ten years before they fall due. To address the mounting problems of water scarcity and malnutrition, we need a strategy to assist farmers to produce staples for basic food security while, at the same time, increasing the production of high-value and nutrient-dense crops.

This report investigates the relationship between water and nutrition using data from Ethiopia on yield, water productivity, and the macro and micronutrient contents of foods. Ethiopia is challenged by erratic rainfall and dry spells. With limited capacity to cope with risks, smallholder farmers concentrate on staple crops, chiefly maize, teff, pulses and oilseeds. Low yields, low water productivity, and a lack of diversification of cropping patterns have had severe consequences for food security and nutrition.

The report uses a nutritional water productivity (NWP) framework to interpret the relationship between nutrition and water in the context of water challenges. It argues that higher yields – of both staple and nutritious crops – are possible, even in water-stressed areas. This will require an agricultural transformation that ensures that efforts to enhance water productivity are linked to the promotion of healthy diets. Increasing water productivity and stabilizing yields at realistic levels will also be crucial to increasing the resilience of farmers. Better coordination and timing of water and other inputs, notably fertilizers and improved seeds, is likely to enhance productivity and to reduce the threats of a further encroachment of agriculture into other ecosystems. A diversified production system is required for food security, nutrition and poverty alleviation. There is an opportunity to provide strategic support for crops and other farm produce with high economic and nutritional value. A range of crops and other produce can be included in farming systems ranging from rainfed to irrigated agriculture. For the farmers to be stimulated and able to capitalize on the increasing need and demand for such produce, the development of markets, and associated investments in cold storage, roads/transport and food procurement programmes that prioritize nutritious produce will be key.

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