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Review

Yield Gaps of Major Cereal and Grain Legume Crops in Ethiopia: A Review

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Abstract: In Ethiopia, smallholder farmers are responsible for most food production. Though yield levels in grain crops have improved greatly over the years, they are still much lower than their potential. The source of yield improvements and the causes of those yield gaps are not well understood. To explain the drivers of yield gaps and current sources of yield improvements in four major cereals (teff, maize, wheat, and sorghum) and three grain legumes (faba bean, common bean, and soybean), we accessed the databases of the Global Yield Gap Atlas, the Food and Agriculture Organization of the United Nations, and the Central Statistical Agency of Ethiopia. Refereed journal articles and grey literature were sought in online databases using keywords. The results showed large increases in production of grain crops with little or no increase in areas of production. The yield increases were primarily attributed to genetic gain rather than agronomic improvements. Farmers' yields remain far lower than those from on-farm trials and on-station trials and the calculated water-limited yield potential. Currently, yields of wheat, maize, sorghum, and common bean in Ethiopia are about 26.8, 19.7, 29.3, and 35.5% of their water-limited yield potentials. Significant portions of the yield gaps stem from low adoption and use of improved varieties, low application of inputs, continual usage of un-optimized crop management practices, and uncontrolled biotic and abiotic stresses. Proper application of fertilizers and use of improved varieties increase yield by 2 to 3 fold and 24–160%, respectively. Cereal-legume intercropping and crop rotation practices increase yield while reducing severity of pests and the need for application of synthetic fertilizers. In contrast, abiotic stresses cause yield reductions of 20–100%. Hence, dissection of the water-limited yield gap in terms of technology, resource, and efficiency yield gaps will allow the prioritization of the most effective intervention areas.

Keywords: yield potential; yield gap; water-limited yield; teff; maize; sorghum; wheat; faba bean; common bean; soybean



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1. Introduction

Agriculture is the main livelihood source for most of the Ethiopian population. Several cereals and grain legumes are grown in the country by smallholder farmers. Productivity of grain crops in the country suffers from large yield gaps arising from many factors. Ethiopian smallholder agriculture is characterized as low-input, low-output, labor-intensive, and rain-dependent [1], with a fragmented landholding system. It involves high crop diversity in both time and space, providing food for family use, and the surplus is taken to the market, which is an indigenous strategy to maximize benefits while reducing natural risks of crop failure.

Until recently, about 40% of crop production increase in the country was due to increase in areas of production [2]. Traditionally, farms are shared among children, so farm size has

decreased as the population has grown. There is little opportunity for young people to get off the land. Food surplus is needed for both cities and countryside. Currently, little suitable new land is left for agricultural expansion, necessitating an increase in crop productivity per unit of land. Farmland intensification through best use of inputs such as improved cultivars, fertilizers, pesticides, and agronomic practices is part of the solution. Since the start of agricultural research in the country, many improved cultivars with high yielding ability, adaptability, and enhanced quality have been released [3]. The use of improved cultivar seeds alone has been reported to increase yield by 60% in cross-pollinated crops and by 30% in self-pollinated crops [4]. Farmers using improved cultivars are encouraged to apply inputs such as fertilizers and modern agronomic practices [5]. However, nationally only about 10–20% of seeds sown by smallholder farmers are of improved cultivars [6]. Even so, this figure is merely for a few selected cereals, and shortage of improved cultivars for grain legumes is commonplace. As a result, as compared to the crop improvements made so far, the country has not fully reaped the benefits of yield gain. Low adoption rates of improved inputs and accompanying modern agricultural practices on one side and imbalances in demand and supply of the needed technology in time and space on the other side, along with limited financial capacity to purchase the available technology, are mainly responsible for the large yield gap. Hence, the greatest opportunities for smallholder farmers to narrow the existing yield gap is by intensification of the production system [7]. With intensification, the use of modern cultivars, crop nutrition inputs, plant protection products, and updated tools and technologies and postharvest handling and processing methods is expected to lead for improved productivity.

Farmer yields (actual yields, Y_a) and on-farm and on-station trial yields all show that these yields are by far lower than the water-limited yield potential (Y_w) indicated in the Global Yield Gap Atlas (GYGA). For example, farmers attained only 19.7% of that of maize and 35.5% of that of common bean water Y_w [8]. Though yield has improved noticeably in the last five decades, yield levels in grain crops are still very low relative to the potential they exhibit in research improvements. Improving productivity of crops and ensuring food self-sufficiency and food security is a national priority. However, the source of yield improvements across the years and the causes of greater yield gaps among grain crops are not well understood. In order to explain the existing yield gaps and to identify areas of improvements, detailed understanding of the yield-defining factors, mainly crop management practices, the functioning seed system, input usage, and their application, are important. Therefore, this paper analyzes the drivers of yield gaps, current sources of yield improvements, and crop management factors contributing to the intensification of the farming systems in four major cereals: teff (*Eragrostis tef* (Zucc.) Trotter), maize (*Zea mays* L.), wheat (*Triticum aestivum* L.), and sorghum (*Sorghum bicolor* (L.) Moench), and three major grain-legumes: faba bean (*Vicia faba* L.), common bean (*Phaseolus vulgaris* L.), and soybean (*Glycine max* (L.) Merrill) in Ethiopia and recommends enabling conditions to narrow the yield gaps.

2. Materials and Methods

2.1. Definitions, Notions and Calculations

According to www.yieldgap.org (accessed on 21 April 2021), yield potential (Y_p) is the yield of a crop cultivar grown under no limitation of water and nutrients, with full control of biotic stresses, and it is determined by solar radiation, temperature, atmospheric CO_2 concentration, and genetic characteristics of the cultivar. In Ethiopia, smallholder farmers grow field crops in a rainfed cropping system with or without the application of improved inputs and agronomic practices. Similarly, research yields from on-farm and on-station trials are from rainfed conditions, but with the application of recommended rate of fertilizers and agronomic management practices. Hence, for rainfed crops, water-limited yield potential (Y_w) is an important point of reference, whereby a crop is grown in limited water supply but not under nutrient and biotic stresses. For actual yield (Y_a), a 10-year average is taken of rainfed crop yield achieved by farmers in a given region under the

dominant current management practices (sowing date, cultivar maturity, and plant density) and soil properties. Yield gap (Yg) is the difference between Y_p or Y_w and Y_a (i.e., $Y_p - Y_a$ or $Y_w - Y_a$). In this discussion, percent of achieved yield by the farmer was calculated as (a ratio of Y_a against on-farm or on-station or highest experimental yield) $\times 100$.

2.2. Data Acquisitions and Analysis

Printed literature was obtained from the libraries of Amhara Regional Agricultural Research Institute (ARARI), Bahir Dar University, and Ethiopian Institute of Agricultural Research (EIAR) in January and February 2021. Soil data came from Bahir Dar Soil Testing and Fertility Improvement Center. The website of Central Statistical Agency (CSA) of Ethiopia (www.csa.gov.et, accessed on 12 January 2021 and 22 February 2022) provided data on annual crop production and land area, crop utilization, and farm management practices. Additional data on crop production and yield were sought from Food and Agricultural Organization of the United Nations (<https://www.fao.org/faostat>, accessed on 24 February 2021). Referred journal articles and grey literature were sought in online literature databases using keywords for targeted scientific information and integrated during the review process.

Annual yield increase rates were obtained by linear regression from 10 years of CSA production data between the 2010/2011 and 2019/2020 production seasons. These data were compared with on-farm trial, on-station trial, and highest experimental yields attained in the field. Data on the number and type of released varieties and on-farm and on-station trial yields were collected from serial publications on plant variety released by Ethiopian Ministry of Agriculture (MoA). Highest experimental yields were obtained from available published and grey literature sources. Whenever available, data on actual and water-limited yield potential (Y_w) were retrieved from global yield gap atlas (GYGA) (www.yieldgap.org, accessed on 21 April 2021 and 24 January 2022). Data on the use of fertilizers and seeds of improved cultivars were drawn from CSA (2019/2020).

3. Results

3.1. Cereals and Grain Legumes: Status and Crop Improvements in Ethiopia

Cereals and grain legumes are important staple food crops in Ethiopia, covering 87 and 10% of the total annual grain production in the country, respectively. Among the cereals, teff, maize, sorghum, and wheat cover nearly 86% of the total area and production of cereals, and faba bean, common bean, and soybean cover about 50% the total area and production of legumes in the country. Within the last decade, the annual production increase in teff, maize, sorghum, and wheat in the country was encouraging (Figure 1). Annually, the production of teff has been increasing by 7.4%, maize by 9.8%, sorghum by 4.6%, and wheat by 9.4%; annual area increases were at 1.5, 1.8, 0.1, and 1.9%, and yield increases per hectare were 5.3 (66.4 kg/ha), 6.8 (171.6 kg/ha), 4.6 (95.7 kg/ha), and 6.5% (120.0 kg/ha), respectively. Thus, the observed increase in production is largely the outcome of improved productivity of these crops (Figure 1 and Supplemental Table S1).

Similarly, increase in annual production (and yield per ha) of faba bean, common bean, and soybean were 4.0 (76.3 kg/ha), 4.3 (56.0 kg/ha), and 75.3% (81.2 kg/ha), respectively (Figure 2). The annual production area of faba bean and common bean has been shrinking by 0.9 and 0.7%, while that of soybean has been expanding by 41.0% from a very low start (Supplemental Table S1). The sole reason for the observed increase in production of faba bean and common bean was thus the increase, in per hectare yield of 5.0 and 4.0%, respectively, where that of soybean was mostly from increase in production area and partly from increase in productivity (5.8%).

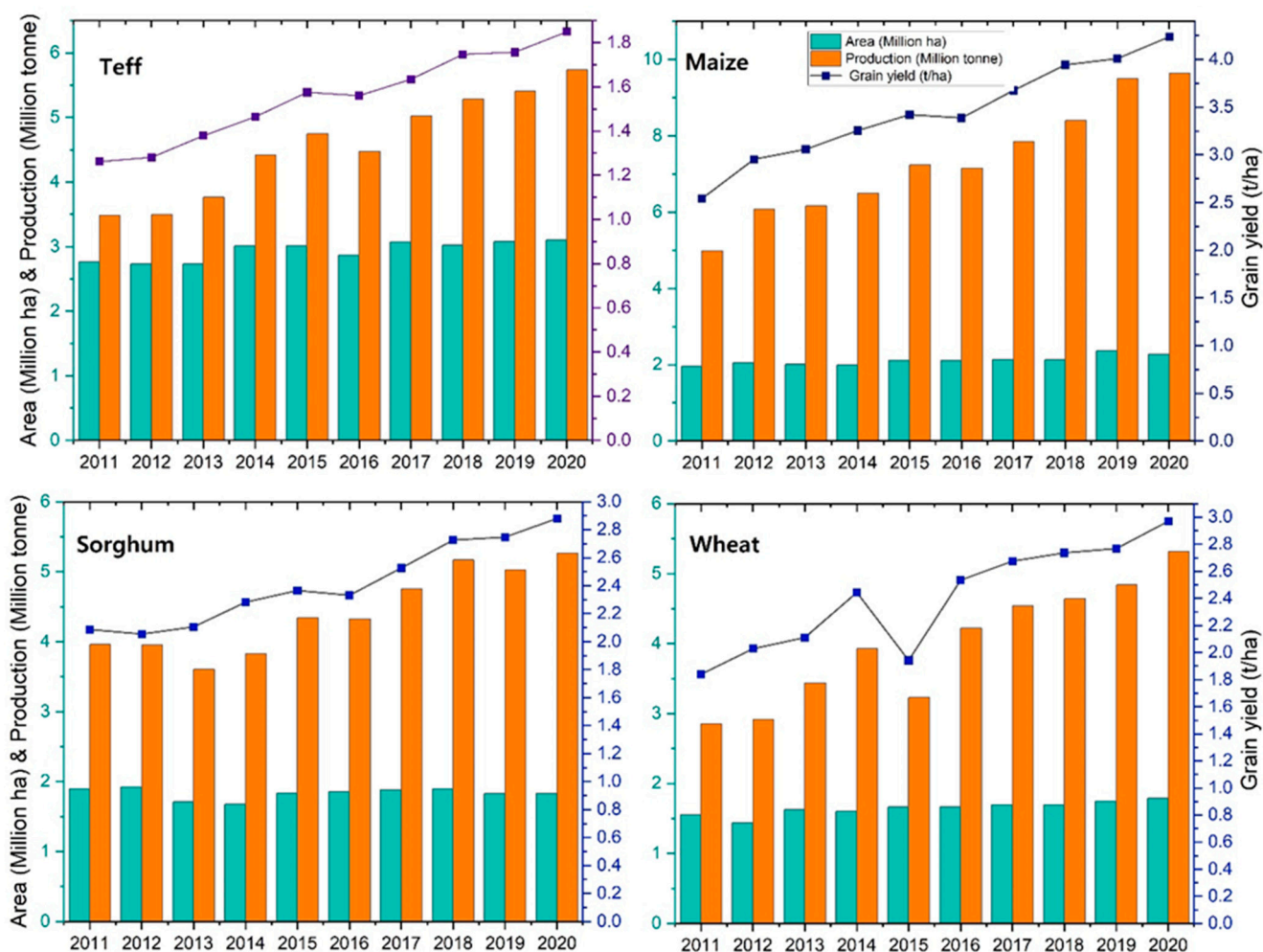


Figure 1. Changes in area, production, and yield of cereal crops between 2011 and 2020.

Since the start of crop research in the country in the 1950s [9–11], 501 cereal and 277 grain legume varieties have been released (EAA 2021) (Supplemental Table S2). The goal of crop research in Ethiopia is to improve productivity through breeding for high yield, grain quality, adaptation, and tolerance to biotic and abiotic stresses [9], and through bettering agronomic and crop protection practices [12]. Ecological adaptation targets phenological traits developed for wider [13] and specific [14] agro-ecological conditions. Wheat of the cereals and common bean of the legumes are the most researched crops in Ethiopia. Given these 9-fold differences in cropped areas between cereals and legumes, the 2-fold difference in number of released cultivars indicates the importance of plant protein in the country. Moreover, these cultivars of both cereals and legumes have been released with crop production and management methods appropriate to local conditions and agro-ecological considerations [3,15–19].

Over the years, cumulative genetic yield gains have been large. Between 1970 and 2012, the gain in teff yield was 1085.7 kg/ha, the highest in 42 years [20]. The gain in highland, mid-land, and lowland maize was 2430, 1711, and –32 kg/ha, respectively, calculated over 39, 29, and 12 years between 1973 and 2015 [21]. Between 1949 and 1987, the gain in yield of wheat was 2938 kg/ha over 38 years [22]. In faba bean, greater improvements were attained in grain yield, bean size, and decrease in chocolate spot disease [23], quantified as cumulative gains of 288.4 kg/ha (8.1%), 266.3 g/bean (51.1%), and –8.9%, respectively between 1974 and 2007 [24]. There has been a clear move to transform production from the traditional Ethiopian small seeded minor types to equine (medium) and major (large seeded) types. The overall grain yield gain in common bean over 26 years (1972 to 1998)

was 1604 kg/ha (82.4%) [25]. Given the efforts made by crop scientists and the enormous improvements made so far, the impact on production and productivity of crops is relatively small. All crops under discussion suffer from a large yield gap. For the country to attain self-sufficiency in cereals by 2050, the current yield must increase by 2.5 fold [26]. At present, about 25% of the domestic wheat demand is covered by import [27].

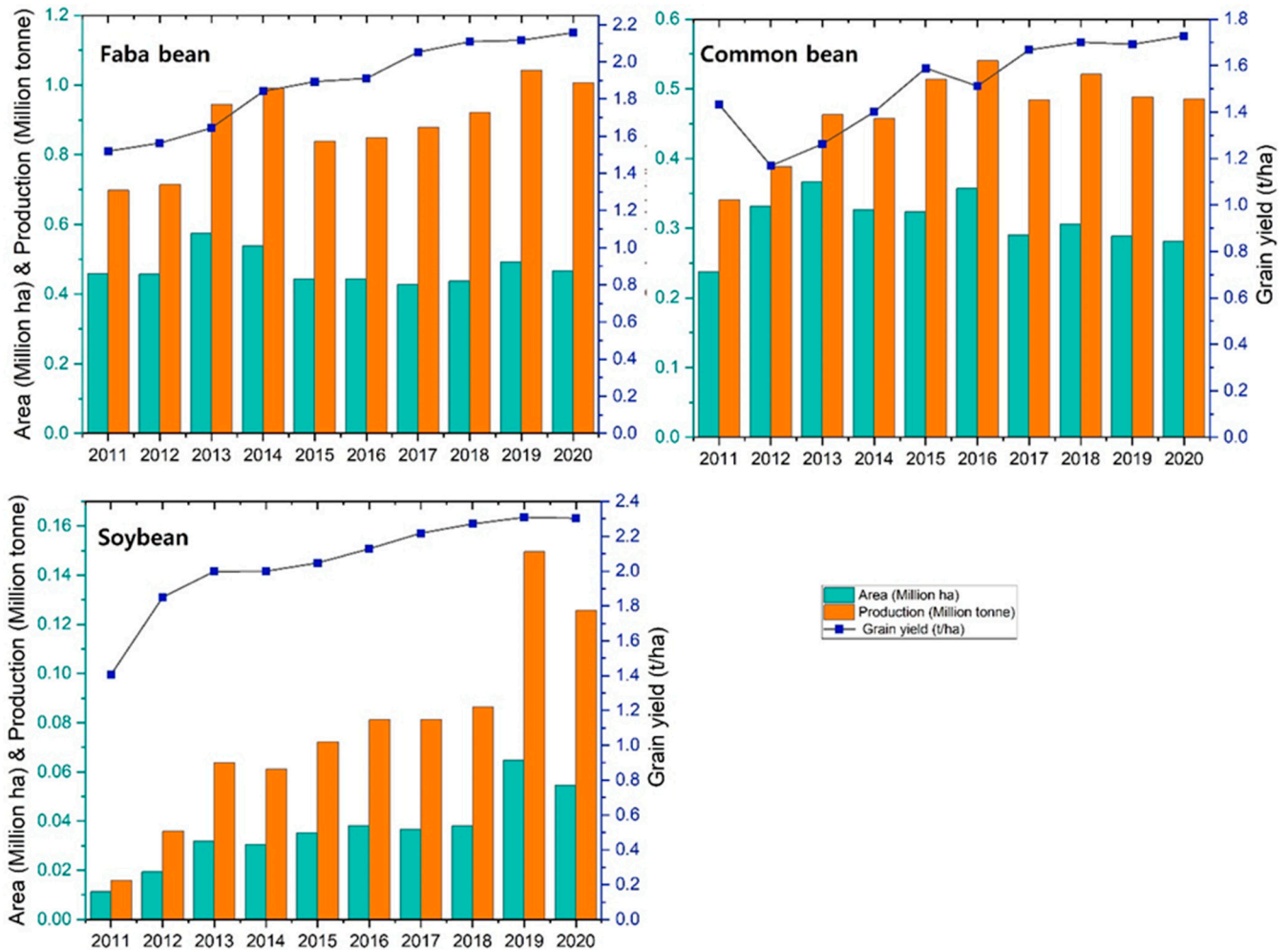


Figure 2. Changes in area, production, and yield of grain legume crops between 2011 and 2020.

3.2. Yield Potential and Yield Gap in Ethiopian Cropping System

Cereal and grain legume productivity has thus increased considerably in the last decade (Figures 1 and 2). Nevertheless, farmers' yields (actual yields, Y_a) are by far lower than both the on-farm and on-station trial yields (Table 1) and the water-limited yield potential (Y_w) [8] that can be achieved under rainfed production systems.

Currently, wheat, maize, sorghum, and common bean yields in Ethiopia are about 26.8, 19.7, 29.3, and 35.5% of their water-limited yield potentials (Table 2), suggesting a considerable scope to increase the productivity of these crops in the country. And in spite of its importance and potential for improvement, the productivity of teff compared to other cereals, such as wheat, sorghum, and maize, is very low (Table 1). The comparison of the national average yield of teff as 1.6 t/ha with that of on-farm, on-station, and the highest experimental yields of 1.8 t/ha, 2.3 t/ha, and 4.9 t/ha, respectively, indicates a huge yield gap. Similarly, comparison of the average actual yield of faba bean and soybean with that of trial stations and highest experimental yield tells the same story. Generally, the mean average actual yield of these cereals is 50 and 65% lower than on-station and highest experimental yields, and that of legumes is 41 and 69% lower.

Table 1. Yield gap indicators in major grain legumes and cereals.

Crop Category	Grain Yield Tonne/ha				Varieties Considered On-Farm and On-Station Trial Yield	References
	Average Actual Yield	On-Farm Trial Yield	On-Station Trial Yield	Highest Experimental Yield		
Teff	1.6	2.2	2.8	4.9	4	[20]
Maize	3.5	6.5	8.1	11.6	6	[29]
Sorghum	2.4	3.3	4.2	5.3	5	[30]
Wheat *	2.4	3.7	4.5	6.6	10	[22] [15–19,28]
Faba bean	1.9	3.1	4.1	6.7	5	[24]
Common bean **	1.5	2.4	2.9	4.6	5	[31]
Soybean	2.1	1.7	2.4	6.6	4	[31]

* wheat is bread and durum wheat, ** common bean is red and white common beans. **Key:** Average actual yield is farm yield, which is the national average yield obtained from farming landholdings. On-farm and on-station yields are yield obtained by controlled experimentation by NARS. Highest experimental yields are yields of varieties tested by researchers in different parts of the country.

Table 2. Yield potential (Y_p), water-limited yield potential (Y_w), and actual yield (Y_a) of some crops available in Global Yield Gap Atlas for Ethiopia.

Crop	Harvest Year	Yield Is Tonne/ha			$(Y_a/Y_w) \times 100$
		Y_a	Y_w	Y_p	
Common bean	2003–2012	1.2	3.4	3.4	35.5
Maize	2005–2017	2.8	14.3	15.8	19.7
Sorghum	2005–2017	2.0	6.9	9.1	29.3
Wheat	2005–2017	2.2	8.3	9.6	26.8

Source: GYGA [8] (www.yieldgap.org, accessed on 24 January 2022).

However, this does not show the complete picture of the causes of yield gaps in Ethiopia. Dissection of the water-limited yield gap in terms of technology, resource, and efficiency will allow the identification of yield-defining factors for specific growing environments. For example, about 50% of wheat [27] and 54–73% of maize [32] yield gaps in water-limited yield potential are attributed to technology and arise from limited use of modern agronomic practices and improved inputs. This indicates the existing potential to increase the yield by more than 2 fold only through application of the available improved production technologies. Furthermore, the yield gaps for different crops vary from region to region. In the central rift valley of Ethiopia, the average yield gap of maize was 4.0 to 9.0 t/ha and that of wheat 2.5 to 4.7 t/ha between 2004 and 2009 [33]. This large yield gap is attributed to the use of unproductive cultivars, low application of N and P in the farm fields, along with susceptibility to biotic and abiotic stresses including diseases, drought, and soil acidity. The different wheat producing districts of Ethiopia yield between 10 and 87% of their locally attainable yield/ha [34], showing that the wide variability in yield across the wheat growing regions of the country related to their ecological specificity. Hence, identification of the contributors of crop yields and the associated yield gap factors specific to different agro-ecological zones will help to prioritize areas of intervention and resource allocation in the effort to narrow the existing yield gaps.

3.3. Cropping Practices in Ethiopia

Ethiopia is classified into 39 agro-ecological zones based on variations in altitude, temperature, rainfall, and soil conditions [13]. This diversity creates potential for the production of a wide range of crops in its central cool, wet, and dry highlands and midlands, and peripheral hot lowlands. In most crop-growing regions, the farming system is mainly a mixed crop–livestock production system involving limited application of modern

agricultural inputs and irrigation water. Average landholding by small-scale farmers is less than one hectare, animal draft power is applied for land preparation, and nearly all smallholder grain production is rainfed. Ethiopian crop agriculture is cereal-dominated. In spite of the importance of grain legumes as sources of protein, most Ethiopian farmers believe often that legumes do better if planted in marginal lands or that legumes do not require fertile land [12], which may be part of the reason for their low productivity. Hence, farmers devote their fertile lands to cereals and marginal lands to the grain legumes. Minimum tillage and no weeding are also common cultural practices in the production of legumes [12]. Rotation and intercropping of cereals and grain legumes is a common practice to maximize yield and reduce the risk of crop failure.

Teff is an endemic crop to Ethiopia and a daily staple food for about 70% of the people in the country [35]. In the 2019/20 production season, 7.2 million [Ethiopian] farming households grew teff on 3.1 million ha of land. Teff shows great diversity in terms of yielding ability, adaptability to a range of environments, phenology, and tolerance to biotic and abiotic stresses. As a result, it is favored by Ethiopian farmers [36] and considered a low-risk crop against stresses and postharvest storage losses [37]. The tiny nature of teff seed makes sowing difficult, and farmers broadcast seeds at a rate of 45 kg/ha [38], while the recommended rate is 10–15 kg/ha when row planted or 25–30 kg/ha when broadcasted (Supplemental Table S3). Di-ammonium phosphate (DAP) (100 kg/ha) is applied at the time of sowing and urea (78 kg/ha) top-dressed later [38], but the rate varies with soil types and cropping system. Teff grows during the main rainy season between July and December and is harvested in January and February, 60 to 140 days after sowing [39]. The low yield of teff (Table 1) is a consequence of low adoption of research outputs by farmers, low yielding ability of landraces, and the susceptibility of the crop to lodging [40]. The direct grain yield loss due to lodging reaches up to 25%, and the indirect loss arises from the limited use of inputs to reduce lodging itself [39]. Because teff is only of national importance and is not a crop with global importance, such as rice and wheat, its improvement research lacks attention from the international scientific community [35,41].

Maize mainly grows in the mid- and low-altitude sub-humid agro-ecologies of the country [42], whereas wheat and sorghum grow in low, mid, and high altitudes [19,43]. The drought-tolerance traits of sorghum allow it to thrive in drought-prone semi-arid lowland areas [44], but this is not without a yield penalty. In lowland areas, wheat is grown with the help of furrow irrigation. In drought-prone lowlands, maize production is largely low-input because of the subsistence nature of the production system [45], and when irrigated, high yield is expected [46]. Few improved maize varieties are suitable for highland areas above 2000 m amsl, and smallholder farmers in this agricultural environment grow local low-yielding varieties [47]. In the last decade, the area of maize production has doubled (Figure 1). The main drivers for the expansion of maize production area are the replacement of sorghum by maize in the rift valley and the adoption of maize by teff-growing farmers in the Amhara Region [10]. Suitable rainfall and fertilizer rates are indicated in Supplemental Table S3. However, the recommended amount of fertilizer depends on soil type, the fertility, and moisture status, as well as the cultivar.

Faba bean is adapted to the cool central highlands receiving 700 to 1200 mm annual rainfall (Supplemental Table S3) and is widely grown in Nitisol and Vertisol agricultural regions [48]. Adaptable improved cultivars have been developed to suit mid and high altitudes between 1200 and 3000 m asl [16–19]. Development of specific cultivars for such mega-environments aims to increase yield stability by minimizing the effect of genotype-by-environment interactions on grain yield. Collections of local landraces and introduction of target accessions from ICARDA for larger seed size and chocolate-spot disease resistance are main sources of germplasm for breeding of faba bean [23]. Ethiopian faba bean genotypes show high genetic diversity derived from these diverse introductions [49], which is independent of the geographical diversity of faba bean-growing regions of the country [50]. Lack of weed control and fertilization [51] and the intrinsically low yielding potential of landraces [23] are among challenges in faba bean production in the country. Use of

improved cultivars, row planting rather than broadcasting, twice weeding, and application of 100 kg DAP/ha resulted in greater gross marginal return rates and a yield benefit of 1.86 t/ha [51].

Common bean is an important protein crop in lowland and mid-altitude agricultural regions [52]. It grows best between 1200 and 2200 m asl, receiving mean annual rainfall of 350–500 mm [53], and prefers deep soil with pH range of 5.8–6.5 [54]. It is a fast-maturing crop [16–19] and can be especially important in areas experiencing terminal drought. Great diversity exists in local landraces [55] and among improved varieties [56]. As a result, ranges of genotypes with varied grain size and color types grow in the country, where the white and red beans are the common types. Variability in days to maturity ranging between 76 and 106 days [57] and about 2.4 t/ha grain yield differences among varieties [58] were reported. Mismatch between varieties and production environments widens the yield gap due to instability of yield resulting from genotype-by-environment interaction [54]. With the environment and the variety responsible for 50% and 29% variation, larger genotype-by-environment interaction reaching 21% is the main problem in selecting stable and widely adapted varieties [54].

Soybean was introduced to Ethiopia in the 1950s. Its production and area coverage have been increasing from time to time (Figure 2). Unlike other farm-produced crops, about 62% of soybean is marketed and only 20% consumed at home. Sole cropping is the most common cropping system. The optimum spacing for medium and late varieties is 60 cm between rows and 5 cm between plants, whereas for early varieties it is 40 and 5 cm between rows and plants, respectively. The commonly used seed rate ranges between 60 and 70 kg/ha for broadcast sowing. Application of 18/46 N/P₂O₅ kg/ha is widely practiced. Experimental results in different localities show that N rate can be increased to 46 kg/ha [59,60].

3.4. Adoption of Improved Technologies and Farmers' Cultivar Choice

Developing and promoting appropriate improved inputs and production technologies and making them accessible with affordable prices are important steps in enhancing agricultural productivity. For many reasons, however, the adoption of innovative technologies by smallholder farmers is poor, so increases in production and productivity of crops have been below their potential (Tables 1 and 2). In the 2019 growing season, at the national level, 82% of cereals and 98% of grain legume fields were grown by smallholder farmers to own (farm-saved) seeds or seeds of local origin. While more than 93% of the teff crop was grown from local or farm-saved seeds, 56% of maize and 17% of wheat hectares were sown to improved cultivars (Figure 3A). Similarly, only about 3% of faba bean and common bean are grown from improved variety seeds, and data for soybean is not available (Figure 3B). On the other hand, 74% of cereals and 33% grain legume fields received synthetic fertilizers at the rate of 54:38 kg/ha N:P₂O₅ and 28:28 kg/ha N:P₂O₅, respectively (Supplemental Table S4).

The amount of fertilizers applied in terms of N and P₂O₅ per unit area was not uniform, ranging from 14/8 kg/ha N/P₂O₅ for sorghum to 79/48 kg/ha N/P₂O₅ for wheat and maize. These values are much lower for legumes: 16/20 kg/ha N/P₂O₅ for common bean to 27/29 kg/ha N/P₂O₅ for faba bean (Supplemental Table S3). However, rates of application have been increasing. For example, the application of fertilizer in maize increased from 34 kg/ha between 1990 and 2013 [10] to 125 kg/ha in 2019, and yield gains for maize increased from an annual rate of 68 kg/ha between 1990 and 2013 [10] to 172 kg/ha by 2019, which is a 2.5-fold increase within two decades. On the other hand, the level of irrigation use in the country by smallholder farmers is very low, with only about 0.21 million ha (1.4% of all agricultural lands) of land being irrigated, of which 0.08 million ha was used mainly for the production of maize followed by sorghum and teff.

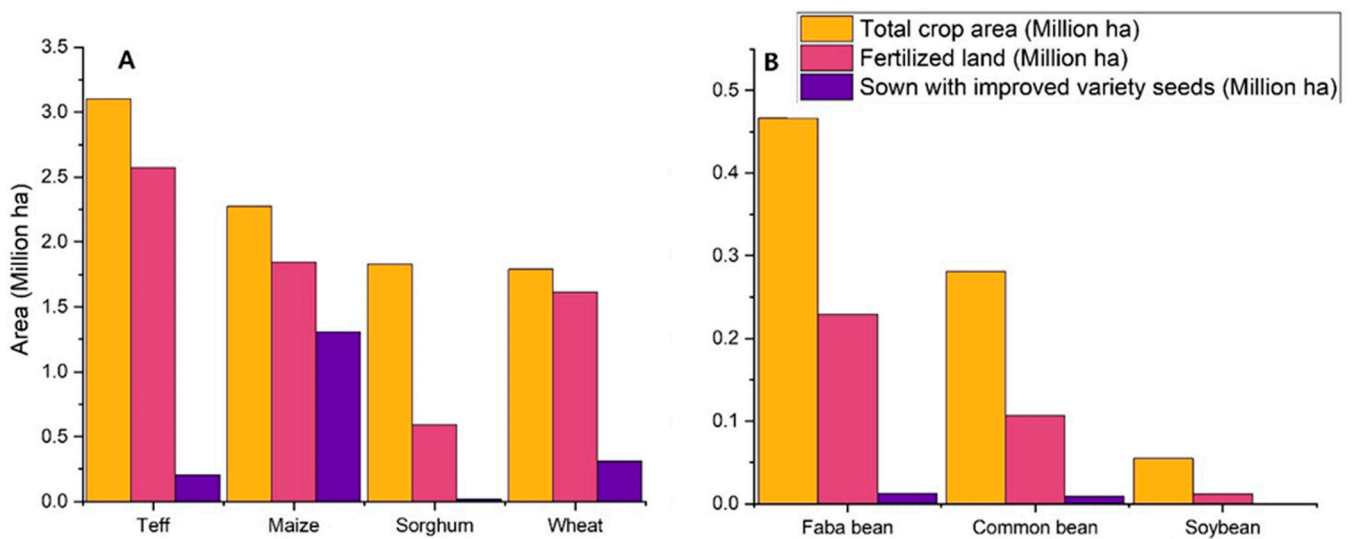


Figure 3. Application of fertilizer and improved variety seeds in selected cereals (A) and grain legumes (B).

Adoption of improved production technologies varies with agricultural regions. In the Central Rift Valley, about 83% of the farmers were adopters of improved common bean varieties, and about 71% of growers used chemical fertilizers [61], rates far higher than the national average. In the central highlands of Ethiopia, a survey indicated that 19% of faba bean growers were adopters of improved seed varieties [62], and the adopters obtained 42% more yield than non-adopter farmers [63]. Similarly, adopters of improved wheat achieve 43% (up to 2.5 t/ha) more yield than non-adopters [64]. Even so, as the replacement rate of old varieties by new ones is very slow, those adoption rates reported may not refer to the latest varieties, which often remain on the shelf [65]. Seed recycling among adopters is a common practice mainly due to limited supply of improved new seed varieties by the formal seed system [66]. Recycling age of improved varieties is negatively correlated with their productivity, where up to 66% yield decline was observed in varieties recycled for more than 10 years [67]. On the other hand, application of some inputs is abandoned by farmers due to economic reasons. Among these, chemical fertilizer is considered expensive, and little or no synthetic fertilizer is applied on grain legumes [9]. As a result, only half of faba bean fields, 40% of common bean fields, and 20% soybean fields were fertilized in 2019. Generally, the use of improved varieties increases yield by more than 59% in maize and up to 86% in common bean and 160% in soybean, and application of the proper amount of N and P fertilizers increases productivity 2 to 3 fold in these crops (Table 3).

Table 3. Yield increases due to the use of improved variety seeds and proper fertilization of the cropping field.

Crop	Improved Variety Use (%)	Fertilizer Use (%)			References
		N	P ₂ O ₅	N + P ₂ O ₅	
Teff	24	32	99	100	[20,68–71]
Maize	59	62	41	84	[21,72–77]
Sorghum	30	169	90	310	[78–80]
Wheat	43	91	63	176	[22,51,64,81]
Faba bean	42	76	94	221	[24,63,82–85]
Common bean	86	68	60	107	[25,86–89]
Soybean	160	125	159	145	[60,90,91]

Because of inadequate adoption of improved production technologies, production and productivity of cereals and grain legumes are far below the potential of these crops. Comparison of yields with African and global averages indicated better actual national yield for sorghum and common bean, but similar comparison for all of the crops against the highest African and global yields showed the greatest yield gap (Supplemental Table S5) [92]. Therefore, the annual increase in production discussed above may be partly due to the increased use of fertilizers and partly from yield increases arising from high yielding landraces resulting from continuous mass selection by farmers. In Ethiopia, an average yield increase of 5% per year through mass selection of landraces by farmers has been reported [5]. However, it can be concluded that the potentials of improved varieties in boosting yield across the country are less exploited, indicating the need for enhanced technology for seed multiplication, input delivery, and marketing systems in the country.

Low adoption of improved agricultural production technologies may arise from many contributing factors. Most often, poor availability of improved varieties forces farmers to keep their own seeds from the previous season and to recycle them over several generations [65]. Furthermore, adaptation, marketing, and local use factors affect farmers' varietal choice. According to de Boef and Bishaw [5], improved varieties often do not respond well in unfavorable low-input and uneven production areas, where farmers often have better adapted and better performing landraces than the improved ones and suitable for the preparation of traditional foods. In eastern Ethiopia, due to lack of improved maize varieties that combine the traits of interest, farmers usually retain their preferred but low-yielding local varieties [93]. Similarly, modern varieties of sorghum were less adopted by farmers in preference to their own varieties [53]; hence, farmer-developed varieties are the main source of sorghum production in certain areas [94]. In the 2019 cropping season, 99% of sorghum farmers used indigenous seeds (Figure 3A). This may be due to both the higher yield of farmers' (132% more) varieties against improved varieties and to traits preferred by farmers [95], which may also suggest that wrong varieties have been sent to the farmers by seed providers. Farmers' choice of faba bean cultivar is defined by the grain yield, the resistance to chocolate spot disease [96], and earliness and cooking ability (Table 4).

Table 4. Traits governing varietal choice among Ethiopian farmers.

Crop	Farmers' Varietal Choice Parameters (Other Than Yield)	Reference
Faba bean	Seed size, disease resistance, earliness, cooking quality	[62,96]
Common bean	Seed size and color, earliness; resistance to drought, bruchids, and disease	[57,97,98]
Soybean	Earliness, seed size, and disease resistance	[99]
Teff	Grain color and marketability, earliness, lodging resistance	[70,100,101]
Maize	Earliness, plant height, pest and pathogen resistance	[102,103]
Sorghum	Market value, cooking or feed quality, fuelwood	[94,95]
Wheat	Disease resistance, drought tolerance, earliness, suitability for making injera *	[104,105]

* Injera is a pancake traditionally made from teff.

Common bean preferences vary with gender. For men, components of yield are important, whereas women's choices depend on culinary traits [57]. Seed color is an important trait in both teff [38,100] and common bean [97], where white and red colors are premium in the market, respectively. These aspects indicate the importance of farmer participation and market drive during varietal development [106].

3.5. Seed System

Three types of seed systems, namely formal, intermediate, and farmers', are recognized [2]. The intermediate and the farmers' seed systems fall in the category of an informal system. The formal seed system is run by the public sector, it is regulated by government policies and laws, and its overall contribution is relatively minimal. The mandate of the formal

system stretches from breeding to seed distribution. It covers less than 20% of the seed used by farmers [2]. The farmers' seed system, which is the unregulated system, is the major seed supplier of the country, and the intermediate system shares certain features from both. Producer cooperatives or unions that produce Quality Declared Seed represent the intermediary seed system [1,6].

The National Agricultural Research System (NARS) is responsible for the development of improved varieties. Early-stage seeds (pre-basic and basic) are supplied by NARS and Ethiopian Seed Enterprise (ESE) to certified seed producers with no fee of proprietary rights [2], which has discouraged the involvement of international seed enterprises [1]. Stakeholders involved in the production of certified seed include, ESE, Regional Seed Enterprises (RSE), private seed companies, and farmer-based seed producer schemes. Seed companies distribute certified seeds to the ultimate user via local private dealers. Most often, the dearth of early generation seeds (EGS) is the cause of the lack of certified seeds in the country [10], indicating that production of EGS is not in line with demand for certified seeds. These deficiencies, especially in hybrid maize seeds, are reported to initiate seed fraud [107], a problem that is still reported. In Jabitehanan district of the Amhara Region, labelling grain as improved variety seed of a known hybrid maize variety and distributing it to the farmer inflicted dissatisfaction among maize farmers in the 2020 cropping season (personal communication with Yezina Fitihamlak and her team, 5 November 2021).

Since its establishment, the formal seed system is limited to a few major food crops, where wheat and maize are at the forefront in terms of volume of production and sale [107]. Markets for grain legume seeds are relatively small owing to their lower marginal profits [6]. The demand for certified seed among smallholder farmers is higher than the existing supply [1]. However, limited capacity for seed multiplication [1], lack of access to improved seeds of preferred varieties [66], demand and supply imbalance [108], along with high seed price and low distribution efficiency [107] were the biggest problems impeding the use of certified seeds among smallholder farmers in the country.

The farmer seed system is sourced from own saving, other farmers, cooperatives, private traders, and from the office of agriculture [38,41]. Farmer cooperatives and unions distribute seeds acquired from ESE and RSE. The original sources of seeds saved from the previous season and distributed in farmer-to-farmer distribution channels can be from harvests grown from certified seeds, showing that saved seeds are not always of landraces. This aspect of the seed system daunts seed companies and renders breeding of self-pollinated crops such as teff an unattractive business.

According to Clark et al. [109] quality seed is a planting material (seed or clone) that is pest-free (clean), genetically consistent (pure), and capable of establishment (vigorous). Hence, so long as a planting material fulfills these criteria, a landrace, locally recycled improved variety seed or newly released improved variety can be quality seed. An improved variety is one produced by selecting, breeding, or genetic modification of any sort for its improved yield, quality, and/or stress resistance. While the formal seed system supplies quality seeds of improved varieties, the informal system supplies landraces and locally recycled improved varieties. This way, the informal seed system bridges the shortcomings of the formal seed system. Moreover, the contribution of the informal seed system is two-fold: it alleviates local seed supply problems while contributing to the in situ conservation of local landraces. The informal seed system plays the role as community gene bank through maintenance of agrobiodiversity [5] and genetic diversity of crop species [110].

Generally, a well-developed seed system is a pillar of agricultural development and a means to reduce the observed yield gap at local and national levels. The use of improved varieties increases the yield of a crop nearly by half (Table 3), and, combined with the application of modern agronomic practices and inputs, there is potential to narrow the existing yield gap. Ensuring the availability of quality seeds in the right amount, space, time, and affordable price are all that is needed from a well-functioning seed system. However, this is far from achieved as the Ethiopian formal seed system is at its early stage of development and suffers from stagnation [2]. Hence, with concerted effort and

actions among various stakeholders across the value chain, the seed sector needs to have institutional, organizational, technical, and infrastructural capacity to sustainably function and support the needs of the farmer. Strengthening both the formal and informal seed systems will contribute to narrowing the current gap in supply of quality seeds for major and minor agricultural crops in the country. Moreover, mainstreaming the legume seed system to the level of the cereal system will lead to sustainable intensification of smallholder agriculture, while contributing greatly to dietary diversification, nutrition security, and resilience among the low-income groups of the society [65].

3.6. Crop Rotation and Intercropping

Cereals and grain legumes are rotated or intercropped in various ways. In Ethiopia, farmers intercrop cereal-to-cereal (e.g., sorghum/finger millet), cereal-to-legume (maize/common bean) [111], and legume-to-legume (pea/faba bean) [112]. Here, we discuss the importance of grain legumes and cereals as component crops in many cropping systems. Crop mixtures, strip intercrops, and rotation of legumes with cereals are common practices [21]. Grain legume species adaptable to the growing environment of cereals are often part of the cereal–legume production system [102].

Legume–cereal rotation is a long-known mechanism of soil fertility restoration and an alternative way of fallowing. Common bean is rotated with maize, teff, and barley in southwestern Ethiopia, and with teff, sorghum, and wheat in northeastern Ethiopia [97]. Faba bean is grown in rotation with cereals including teff, wheat, and barley and plays a role in soil fertility restoration [16]. Growing of maize after soybean improved maize grain yield by 36% and reduced the calculated need for urea by 46 kg [46].

Intercropping of legumes with cereals and oil crops is a traditional means for soil fertility restoration, maintenance, and improvement. The selection of the intercrops is probably governed by the natural connection to shared agro-ecological adaptations of partner crops [13]. In the central highlands of Ethiopia, mixed cropping of wheat with faba bean at a rate of 175:75 kg/ha resulted a land equivalent ratio of 1.22 and reduced weed biomass and chocolate spot disease score by 9 g/m² and 1.7, respectively [113]. A 1:1 maize:faba bean row planting pattern supplied with 96 kg of DAP and 46 kg of N/ha provided an average of 1.75 LER [112]. Simultaneous establishment of maize and common bean intercrops provided greater yield and yield components to common bean, but 32% more yield in maize was recorded when intercropping of common bean was completed six weeks after maize emergence [111]. Intercropping of maize with soybean at a 2:1 ratio resulted in LER of 1.6 [102]. In a maize–common bean single alternate row intercropping system, LER of 1.7 was recorded. Growing of maize either after Niger seed (*Guizotia abyssinica* L.) or common bean resulted in a greater yield in maize with or without the application of NP fertilizers [113]. Generally, intercropping averts risks in times of crop failure, a means for product diversification with greater combined yield, slows the progress of pests and diseases, and contributes to soil and water conservation. Hence, in countries such as Ethiopia, where fragmented landholding and subsistence farming are dominant in cropping regions, cereal–legume intercropping has many benefits to exploit.

3.7. Fertilization

Poor soil fertility and lack of application of fertilizers reduce productivity of crops in agricultural regions. The natural soil fertility status determines the amount of synthetic fertilizers applied for maximum yield. According to the International Fertilizer Association, the average fertilizer usage in Sub-Saharan Africa is currently 13 kg/ha nutrient, which is far lower than the Abuja Declaration on Fertilizer for the African Green Revolution of 50 kg/ha and the global average of 120 kg/ha (fertilizer.org). The Ethiopian national average application of 91 kg/ha nutrient (54/37 kg/ha N/P₂O₅) for cereals and 56 kg/ha nutrient (28/28 kg/ha N/P₂O₅) for grain legumes has already met the nutrient guidelines set in the Abuja Declaration, but is lower than the global average. In Ethiopia, the soil is considered to be rich in potassium content, so fertilizer application was generally in the

form of DAP and urea [10]. Presently, however, the country has shifted from the traditional DAP fertilizer into the use of blended fertilizers containing nitrogen, phosphate, and sulfur (NPS) with or without zinc, boron, and iron. Urea is applied to supply N.

In various parts of Ethiopia, application of N and P fertilizers improved grain yield significantly. Yield response to the application of fertilizers varies with crop type and growing region. Application of P at the rate of 40 and 26 kg/ha, respectively, improved grain yield of faba bean by 26% [84] and that of common bean by 60% [89] in southern Ethiopia. With the application of the recommended rate of 46:46 kg/ha, N:P fertilizer's yield of common bean variety improved by 64% over the control [114]. Application of P also has a positive impact on nodule quantity in common bean [115]. Similarly, application of starter N fertilizer at the rate of 23 kg/ha and seed inoculation with *Rhizobium* bacteria improved the grain yield by 32% and 39%, respectively [88]. In maize, application of 100:100 kg/ha of P₂O₅:N improved the yield by 72.5% in eastern Ethiopia [77] and by 94.6% in western Ethiopia [76]. Application of 87:46 kg/ha N:P₂O₅ to sorghum improved yield by 4 fold [78]. Wheat fields receiving 138 kg N/ha increased yield by 100% and addition of 69 kg P₂O₅/ha improved yield by 2 fold [81]. Therefore, maintaining the nutritional statuses of the soil greatly improves the yielding ability of grain crops.

To enhance sustainability, it is desirable to integrate nutrient recycling into crop production, which can be accomplished by using organic inputs such as manure and correcting the balance of nutrients to the needs of the crop by means of synthetic fertilizer. For example, application of compost alone resulted in a 69% yield increase in wheat, whereas combined application of compost and a half dose of synthetic fertilizer increased the yield by 112% over the control [116]. Similarly, compared to the control (100% NPK), maize yield and nutritional content was improved more than 3-fold following the combined application of symbiotic bio-fertilizers (with or without slurry) and half-dose NPK fertilizers in Egypt [117]. The combined application of manure with synthetic fertilizer in maize improved both yield and fertilizer use efficiency [118]. The combination of farmyard manure with symbiotic inoculants reduced the effect of water deficit stress on plant growth and yield by improving soil moisture retention, availability, and hydraulic conductivity [118], along with root water uptake [119].

3.8. Inoculants

Rhizobial inoculation improves the number and quality of root nodules and ultimately the amount N fixed from the atmosphere by legumes. Inoculation of faba bean, common bean, and soybean with rhizobia, and application of P fertilizer and starter N, significantly improved grain yield and quality. In faba bean, yield increase of 80, 90, and 155% were recorded due to application of rhizobium inoculants, NPSZnB fertilizer, and the combination of the two, respectively [120]. In common bean, while inoculation improved the number of nodules, addition of starter N improved grain yield significantly [88], and similarly, 23 kg/ha starter N and mixed-strain *Rhizobium phaseoli* inoculant increased yield by 68% and 70%, respectively [121]. Inoculation of common bean and soybean varieties with appropriate bacterial strains resulted in yield gains of 2.1 t/ha (108%) and 1.8 t/ha (63%), respectively [31]. In soybean, as much as 116% yield increase was recorded due to inoculation alone [122]. In maize–common bean intercrops, inoculation alone increased the average yield by 26% and 10%, and combined application of inoculation and N:P fertilizer at the rate of 20:20 kg/ha increased the average yield of common bean and maize by 44 and 29% [46]. In conclusion, application of inoculants alone, or with starter N fertilizer and/or recommended rate of P, increases yield from 26 to 70% in common bean, from 80 to 155% in faba bean, and by about 63 to 116% in soybean.

3.9. Pollination

Cereals are wind-pollinated, whereas the legumes and bee families co-evolved, and many crop legumes rely on insect-mediated pollination, whereas others, such as field pea, self-pollinate. Pollination is an important ecosystem service, and several crops rely at least

partly on insects for pollination. Literature on the use and significance of pollinators in Ethiopia is sparse. In Ethiopia, the economic value of pollination service in grain legumes in 2015/2016 was estimated at 0.21 billion USD [123]. Although insects improved the yield of crops such as faba bean by as much as 46% [124], there is no data on the deliberate use of pollinator insects in Ethiopia. However, in research stations, honeybees are used as a crossing agent in population improvement of faba bean with recurrent selection procedure [23].

3.10. Biotic Stress

The extent of yield loss due to disease infestations, insect damages, and weed competitions depend on the intensity and time of infestation, the virulence of the factor, and vulnerability of the host. In Ethiopia, these biotic factors cause yield loss from 20 to 100% (Table 5). In this subtitle, we discuss in detail taking maize from cereals and faba bean from legumes as examples.

Table 5. Biotic stresses and extent of yield loss in selected crops.

Crop	Biotic Stress	Yield Loss (%) *	Tolerant Varieties	References
Teff	Cutworms (<i>Agrotis</i> spp.)			
	Root rot			
	Teff rust (<i>Uromyces eragrostidis</i>)		Dursi (Acc. 236952)	[19]
Faba bean	Gall disease	100	Dosha, NC 58, Messay, Kassa	[125–127]
	Chocolate spot disease	75	Tumsa, Gebelcho, Mosissa (EH-99047-1)	[16,24,125,127,128]
	Rust		Mosissa,	[16,125]
	Aschochyta blight		Mosissa	[16,125]
	Black root rot		Dida'a, Ashebeka	[1]
	Weeds	49		[129]
Common bean	Alternaria leaf spot, Common bean bacterial blight, and Rust		Wabero, Gobu (Selian-97), Doyo (SAB 627)	[19,130]
	Alternaria leaf spot, Common bean bacterial blight, and Rust, Anthracnose, root rot		Wabero, Gobu (Selian-97), Doyo (SAB 627), Fedis (ECAB0060), Hirna (ECAB 0203), Babile (ECAB 0247)	[16,19]
Soybean	Weed competition	78		[131]
Wheat	Rust (<i>Puccinia</i> spp.)	26	FH4-2-11	[30]
	Septria leaf blotch			
Maize	Fusarium head blight			
	Grey leaf spot (GLS) (<i>Cercospora zea-maydis</i>)	21–37	BH-660	[132]
	Foliar diseases including GLS, TLB, CLR	28–91 (TLB);	BH-546, BH-547, and BH-661	[133]
	MSV		Gambella Composite; Abo-Bako	[133]
	Maize stem borer	7–55	BH-660; CML-395/CML-202//142-1-e	[134]
	Maize weevil	20–100	Horra; Melkasa-7; Melkasa-6Q	[134]
	Weeds	20–100		[72,135]
Sorghum	Anthracnose (<i>Colletotrichum sublineolum</i>)			
	Smuts (<i>Sphacelotheca</i> spp.)	19.4		[136]
	Ergot (<i>Sphacelia sorghi</i>)			
	Grain molds			

* Yield loss is in susceptible varieties.

In Ethiopia, the yielding ability of maize suffers mainly from fungal diseases, insects, and weed competitions. Apart from yield loss, biotic stresses are cause for removal of high yielding crop varieties from the seed system. Beletech and BH541 maize varieties were removed from the seed system due to their susceptibility to turicum leaf blight (TLB) (*Exserohilum turcicum*) [133]. Additionally, grey leaf spot (GLS) (*Cercospora zea-maydis*), common leaf rust (CLR) (*Puccinia sorghi*), and *phaeosphaeria* leaf spot (PLS) are commonly found diseases. Insect pests including maize weevil (*Sitophilus zeamais*) [14,133] in storage, maize stem borers (*Busseola fusca* (Fuller), spotted stem borer (*Chilo partellus* (Swinhoe)) [134], and fall armyworm (*Spodoptera frugiperda* (Smith)) in the field are the common ones. Grain losses due to weevil in traditional maize storage barns reaches 20–100% [134]. Maize is also susceptible to weed competition. Early weeding can be enough for the whole life cycle, but delaying until 12 weeks after emergence can cause yield loss up to 85% [135]. Integration of glyphosate with manual weeding controlled weeds in maize and provided 33.5% yield gain over the control weedy plots, while twice manual weeding showed yield advantage of 31.4% [72].

Faba bean is affected by fungal diseases including chocolate spot (*Botrytis fabae* Sardina), rust (*Uromyces vicia-fabae*), Ascochyta blight (*Ascochyta fabae*), foot rot (*Fusarium avenaceum*), black root rot (*F. solani*) [9,12,125], and now gall disease (*Olpidium viciae*) [125]. Chocolate spot disease is prevalent at 57–100% of faba bean growing regions [125], and yield reductions due to it and gall disease reach 75% and 100%, respectively (Table 5). Combining cultural practices, such as early sowing, and application of fungicides with resistant cultivars and intercropping can reduce the severity of these diseases [125,128]. Insect pests, including African bollworm (*Helicoverpa armigera*) [9] and aphids (*Acyrtosiphon pisum*) in the field and bruchids (*Callosobruchus chinensis*) [12] in storage, are the important pests. The yield penalty due to weed completion in faba bean reaches 41%, and hoeing at seedling stage following twice manual weeding resulted in 51% yield increase over not-weeded plots [129]. Parasitic weeds striga (*Striga hermontica*) in maize [133] and orobanche (*Orobanche crenata*) in faba bean [9] affect productivities of these crops. The faba bean cultivar Hashenge (ILB 4358) is known for its orobanche resistance [18].

3.11. Abiotic Stresses

Abiotic stresses affect growth and development of crops and impact yield performance. In the field, crops experience soil acidity, drought, waterlogging, hail damage, and frost-related stresses [9]. The susceptibility of crop species to abiotic stresses depends on their inherent genetic potential, intensity, and duration of the stress and the stage of crop development [137,138]. In Ethiopia, acid soils occupy 41.0% of the country, and nearly 13.6% of the acid soils have problems of Al^{3+} toxicity [139]. The reclamation of acid soils through application of lime is an expensive method, ineffective in the subsoil, and in some cases, heavy application may have a deleterious effect on the soil structure [140]. Faba bean genotypes were tested for tolerance to root-zone acidity and Al^{3+} -toxicity, and outstanding ones were identified [141], but have yet to be tested under field condition. Frost is prominent when faba bean is grown above 3000 m asl, and hail storms may cause complete crop loss [12]. In the highland Vertisol faba bean growing regions, waterlogging is one of the major abiotic stresses. Limitation of growth and discoloration, and the concomitant exposure of the plant to black root rot disease, are associated with waterlogging problems in faba bean [12]. The EIAR released six faba bean cultivars, including Selale, Wayu, Wolki, Hachalu, Didi'a, and Ashebeke, with tolerance to waterlogging stress [1,15–19].

About 40% of maize is grown in drought-prone areas, and recurrent drought is a source of yield reduction reaching 50 to 72% in these agricultural environments [45]. Since most smallholder farmers have no access to irrigation facilities, maize is mainly grown by rainfed agriculture; hence, development of drought-tolerant varieties is crucial. Known drought-tolerant maize varieties include BH546, BH547, and BH661 [133], and Melkasa1 to Melkasa7 (released between 2000 and 2008) [45]. BH661 is also resistant to major diseases and exhibits wide adaptation [10]. Soybean variety Gezella [1] and sorghum hybrid varieties ESH-1,

ESH-2 [30], and ESH3 [1], all released by EIAR in 2015, are tolerant to moisture deficit. Generally, development of abiotic stress tolerant varieties for these crops increases the area of production and allows better use of marginal lands.

4. Conclusions

In the last decade, productivity of the cereal and grain legume crops under discussion has been increasing at annual rates of 5.8 and 4.9%, respectively. Accordingly, there has been greater increase in production of these crops with little or no increase in area of production. Yet, the farmers are able to achieve only 20–30% of water-limited yield potential for cereals and 28–33% of the highest experimental yields for grain legumes, indicating both the sizable yield gap and the potential to increase the productivity of these crops in the country. Significant portions of yield gaps stem from the inherently low productivity of landraces, low adoption and use of improved varieties, low application of inputs, traditional crop management practices, and biotic and abiotic stresses. These problems by themselves arise from low extension outreach, lack of improved varieties preferred by farmers, supply and demand imbalances, and high price of inputs.

Proper application of fertilizers and use of improved varieties can increase yield by 2 to 3 fold and 24–160%, respectively. Cereal–legume intercropping and crop rotation practices have been reported to increase the yield of companion crops while reducing the need for application of synthetic fertilizers. Application of inoculants alone or with starter N fertilizer and/or recommended rate of P increases yield from 26–116% in the studied legume crops. On the other hand, depending on the severity, biotic and abiotic stresses can cause yield reduction reaching up to 20 to 100%.

In order to improve the sustainability of crop production, it is desirable to develop a suite of inputs, where nutrient cycling is optimized by the use of organic inputs topped up with synthetic fertilizer as necessary, agronomic practices are appropriately adapted to the environment, and improved germplasm is used to take the maximum advantage of these inputs. Future research may focus on the dissection of the water-limited yield gap in terms of technology, resource, and efficiency yield gaps to allow the prioritization of the most effective intervention areas.

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/agronomy12102528/s1>, Table S1: Annual increases in area, production, and productivity and R^2 values in crops from 2011 to 2020, Table S2: New varieties of major cereals and grain legumes released in- and before 2021 through the National Agricultural Research System (NARS) in Ethiopia, Table S3: Ecological adaptation and some agronomic characteristics of cereals and grain legumes, Table S4: CSA 2020, Table S5: Comparison average and highest yields of major cereals and grain legumes from global and African context.

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