FOOD SCIENCE & TECHNOLOGY | REVIEW ARTICLE

Exploiting the genetic potential of tef through improved agronomic practices: a review

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Abstract: Over the past six decades of tef research in Ethiopia, significant progress has been made in quantifying the yield increase in percentage. Regardless of the increase in yield, the overall performance of the crop is still below its potential and there is a large yield gap. The main cause of this yield gap is the use of traditional crop management practices. As a result, production potential of tef varieties has remained low, and most smallholder farmers are benefiting from the potential yield. These calls for the use of advanced crop management strategies in different tef cultivating areas where tef is a priority crops for production. Therefore, our target was to review previous research findings in Ethiopia, with particular interest in crop management practices. This article reviews previous research findings and technology generated on tef production systems. The lack of adoption of improved

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Major theme of research is in improving the level of productivity and long-term sustainability on farm-level management systems that optimize crop yield, quality, and ongoing input costs, while simultaneously improving environmental health and agricultural sustainability. My long term career goals, provision of possible adaptation and mitigation measures against climate change impacts on tef-legume based agro-ecological intensification crop production system for improving food security in sub-Saharan Africa.

PUBLIC INTEREST STATEMENT

Tef (Eragrostis tef) is the most important cereal crop in Ethiopia, where it is the first in terms of acreage and second after maize in grain production volume. The crop is preferred both by farmers and consumers. Farmers benefit since it can be produced under diverse agro-ecological conditions and can be stored for a long time as the grains not affected by storage pests. Ethiopian consumers prefer tef because of its excellent nutritional quality (well-balanced protein and minerals) and it makes good quality “injera”, pancake-like soft bread. Owing to its localized importance as a crop in the world, tef has remained as an “orphan crop” in terms of research and development compared to other cereals. It grossly lacked the attention of international research establishments and donors. In spite of achievements made more than six decades of tef research in Ethiopia, the major constraints in tef husbandry have been its relatively low productivity (national average about 1.75 tha -1) due to widespread use of landraces lacking desirable agronomic traits coupled with traditional husbandry practices. The paper gives a comprehensive overview of the research findings and information generated on the tef sustainable cropping systems, where tef is the staple food crop. We, therefore, generate improved practices and the use of new tools to help improve decisions and that can contribute to closing the exploitable yield gap in tef priorities.
agronomic practices has been identified as a major constraint to tef yield. Furthermore, the crop's due to a small seed nature needs further attention. According to this review, genetically improved variety may not attain their yield potential without a crop management synergy. We, therefore, propose uses of improved agronomic practices and advanced tools for help improve decisions, increase tef yield and contribute to closing yield gap.

**Subjects:** Agriculture & Environmental Sciences; Botany; Soil Sciences

**Keywords:** cropping system; improved practices; knowledge sharing; tools supporting

1. Introduction

Orphan crops are defined as crops that are “unnoticed and underused species (NUS)” (Hall et al., 2013) and “underutilized crops” (Dawson & Jaenicke, 2007). Orphan crops are the best fit to smallholder farmers conditions and satisfy the importance for native humans and mostly adapted a harsh conditions compared to those of global crops such as bread wheat (*Triticum aestivum* L.) and Maize (*Zea mays* L.) (Tadele, 2019). Orphan crops used for food nutrition self-sufficiency and income generation in the developing nations; however, they have not been considerably researched (Kuta et al., 2003 and Tadele, 2014).

Orphan crops belong to the fundamental classes of crops which include cereals, legumes, vegetables, root crops, and fruits and have diverse centers of origin (Food and Agriculture Organization of the United Nations, 2015). Tef (*Eragrostis tef*) is still the most important “orphan” cereal which originated and diversified in Ethiopia (Vavilov, 1951), and over the years the crop species have co-evolved. It is the first in area cultivation (3.1 million ha) and the second in grain production quantity (5.7 million tons) after maize (CSA (Central Statistical Agency), 2020).

Tef is frequently grown as an insurance or rescue crop to preserve the Ethiopian population (Ketema, 1997; Shiferaw & Baker, 1996). Now a days, tef grain accommodates the predominant food grain for over 80 million of the expected 110 million of Ethiopia’s populace. This implies that tef is an essential and valuable crop for the country's overall agricultural system and food self-sufficiency. Tef cultivation is a constitutes a yearly acreage of approximately 3.1 hectares and grain harvest of about 5.75 million tons. Tef accounts for approximately 1/3 of the overall acreage (10.233 million ha) and 1/5 of the gross yearly grain production (26.779 million ton) of all cereals in the country (CSA (Central Statistical Agency), 2020). However, the crop is become an important food and pasture crop in South Africa, India, USA, Pakistan, Uganda, Kenya and Mozambique.

The sustained and massive production of tef by Ethiopian farmers is articulated by its relative advantages over other cereals in both husbandry and utilization aspects. Its primary merits in farming include versatile adaptation with desirable resilience to both low and excessive moisture stresses, value as a catch and cash crop, and minimum postharvest losses due to storage pests. Ethiopians had an overwhelming choice of eating *Injera* (pancake-like bread) made from tef flour because of its specific qualities of excellent water-holding capacity, longer shelf life, unique flavour, pliability, smooth and sleek texture. Tef grains provide 99% flour when processed (Ebba, 1969) and in *Injera* when baked (Tadesse, 1969). Currently, tef grain considerable interest in the global marketplace, due to its gluten-free qualities for those humans allergic to gluten (Spaanjil-Dekking et al., 2005). Hence, the Ethiopian administration has embarked upon fostering the export of tef via increased production to satisfy the domestic demand and convey surplus for exploiting, surging demand on worldwide market for tef and tef products. Apart from grain, tef straw also used for a livestock feed in Ethiopia. According to Seyoum (2001), tef straw has very vital role for livestock feeds in Ethiopia.
Significant progress has been accomplished and impressive successes have been achieved in boosting the production and productivity of tef in Ethiopia. Although the tef subsector's overall performance is currently below its potential, tef output has been expanding in the last 18 years. Production of tef was increased from 1.74 million metric tons in 2000/01 to 5.72 million metric tons in 2019/2020, indicating 8.7% average annual growth rate (CSA (Central Statistical Agency), 2020). Appreciable tef yield increase has been achieved (5.06%) annually in the same period to reach the current yield level of 1.73 metric tons/hectare. The rate of tef farming area extension was projected to be 2.91 per annum, with 63.5% of the overall increment in tef production was due to genetic improvements and 36.5% was due to area expansion. The productivity of improved tef varieties, with recommended agronomic practices, reached 2–3 ton/ha in research fields and 1.8 in farmers. This indicates that there is a yield gap usually obtained in the farmer field compared to the research field.

So far, various research efforts have been done, to determine the agronomic recommendation for tef cultivation. However, much of the information collected has been accounted for climate change, year and seasonal climatic variability (mintewab et al., 2020). Moreover, the research findings have not been supported by advanced tools and technologies. In general, the information generated has not been adequately organized and communicated in applicable way. As a result, the aim of this review is to assess the key crop management practices to improve both yield and sustainable production of tef.

2. Congestion of Tef Cultivation
The productivity of a given variety/cultivar is a function of the combined effect of the individual yield contributing traits which in turn are highly influenced by environmental factors and management practices (Korbu et al., 2020). To improve crop productivity, three key components such as high-yielding varieties, yield-promoting inputs, and recommended agronomic practices must exist in a proper combination highlighted by (Schilt-van Ettekoven et al., 2017). However, tef improvement programs in Ethiopia have been given more research attention on tef breeding such as reducing lodging, improving yield, and drought resistance, but less emphasis has been given agronomic research (R Abraham, 2015). Moreover, poor soil fertility, high population density, weed, soil acidity, poor land preparation, sowing date, sowing methods are the major limiting factors of tef productions in Ethiopia (Haileselassie et al., 2011; Tamene et al., 2017). Moreover, lodging is the most serious problem, particularly in areas that are subjected to high rainfall and strong winds (Tadele & Assefa, 2012).

Therefore, to alleviate the present situation, generating of advanced crop management practices such as seed rate, sowing dates, seedbed preparation, fertilizer type, rate and time of application, and cropping systems (crop rotation and different cropping systems (crop rotation, relay, double and inter-cropping), could be a major contribution to resolve production gap and raise the tef productivity in the country.

3. Tef Agronomy in Ethiopia
In Ethiopia, substantial progress has been made and excellent gains have been recorded in boosting the crop’s yield and production over the last decay in tef research. The tef subsector’s performance remains below its potential, tef production has increased during the last 14 years CSA (Central Statistical Agency), 2020; Figure 1).

The Figure 1 showed that tef production trends, both areas sown and productivity, were an increased trends since 2007–2020 years. These significant increment of tef productivity in the country is mostly by genetic improvement, wide dissemination, and adoption of improved tef varieties coupled with agronomic managements in tef growing regions of the country. Despite the genetic improvement and generated information, about crop management practices by the national and regional agricultural research system, both recognition and adoption of generated
technologies information have been given less recognition by the users, as a result of a high yield gap (40%) of tef productivity in the country (Fikadu et al., 2019).

The major factors contributing to the high yield gaps are inter-annual and inter-seasonal climate variability along with climate change are the main causes of fluctuation in the annual tef production, because tef is mostly produced in rain-fed conditions (Mintewab et al., 2020). The information gap includes the degree of weather variability and change, and climate risks factors, such as the onset and cessation of rainfall, offset duration, and dry spell length, which are major geographical factors influencing all farming activities mainly agronomic management of the crop. Thus, studies on crop management through decision support tools, advanced technology, and improved fertilizer use efficiency at the farm level are the great emphasis for sustainable tef production systems in Ethiopia.

### 3.1. Land Preparation

Due to its extremely small seed size, tef requires firm-level seedbeds, free from clods and stumps (Deckers et al., 2001). Under current farmers’ practices using oxen ploughs, a tef field ploughed 2–5 times in semi-arid areas depending on the soil type and weed conditions (Temesgen, 2007) and 5–8 times in humid areas (Hundera et al., 2001). Several tillage studies were made to determine the optimum frequency of oxen ploughing. A study in North-Western Ethiopia showed that three times oxen plough combined with hand weeding at the tillering stage of the tef plant was the best interim of tef productivity and recommended to small-scale farmers (Balcha, 2014). Another study by Molla and Muhie (2011) suggested 3–6 times oxen plough in the Sheworobit area in central north Ethiopia while 2–4 times in Jemma and Wonchit River valleys. Considering the benefits on soil moisture and nutrient availability, four times oxen ploughing was recommended by Bogole and Le (2014). On the other hand, the recent study in semiarid areas in Minjar and AlemTena showed that the highest grain yield and the net benefit was obtained from reduced tillage (i.e., 2 times ploughing with residue retained) compared to farmers’ practice (5 ploughing) and zero tillage (no-till; Figure 2) but with non-selective herbicides to control weeds (Gezahegn et al., 2018). Moreover, the tillage system can favor timely planting of the crop, reduce the cost of farming, and protect agro-ecological on the long-term basis (Alvaro et al., 2014). Therefore, future research should be needed under different agro-ecologies and soil types to drawn conclusive recommendations.

### 3.2. Seedbed Compaction

To facilitate emergence, tef seeds need medium soil packing to make the land firm so that the tiny tef seeds have good contact with the soil, especially with Vertisols type, which expands upon wetting. Hence, the firm seedbed preparation due to compaction improve the soil moisture from

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**Figure 1. Tef production trend from 2007 to 2020 in Ethiopia (million hectares) and grain yield (kg/ha).**
drying quickly and avoids seed desiccation. Compaction of the seedbed also makes a smooth or flat field, which facilitates the harvesting of the tef plant closer to the soil surface. This maximizes the amount of biomass harvested from the field as tef straw is the most valuable livestock feed (DZARC (Debre zeit Agricultural Research Center), 1989).

Compaction of the seedbed, particularly on Vertisols, is made by trampling by domestic animals, particularly cattle, sheep, donkeys, and sometimes humans (Hundera et al., 2001and; Tari et al., 2007). According to Ketema (1997), trampling of the seedbed is also important to control weeds as the practice buries the young weed plants deep in the soil (Ketema, 1997). On the contrary, a three-year study on two soil types (Inceptisol and Vertisol) at Debre Zeit revealed that seedbed trampling did not have a significant effect on grain yield (Hundera et al., 2001). Temesgen (2007) also reported the importance of tef seedbed trampling and recommended the use of subsoil to break hardpans. In general, if there is moisture stress or rainfall interruption incidence at the beginning of the growing season, moderate compaction of the seedbed is useful to enhance stand establishment on Vertisols that suffer from soil crusting. Otherwise, during years of sufficient rainfall, in areas with reliable and sufficient rainfall for crop growth, compacting the seedbed especially on light soil might not have benefits in promoting germination and stand establishment (Ketema, 1997). As a result, comprehensive investigations with a larger range of testing sites, soil types, and growth seasons may be required to reconcile the contradictory findings.
3.3. Tef Sowing Method
Farmers in Ethiopia mainly use the broadcasting methods for sowing tef. The broadcast method of sowing is less expensive but causes uneven seed distribution and high competition among plants. According to Vandercasteelen et al. (2016), row planting of tef requires 30% more labour than broadcasting (Figure 4). Similar studies showed that row sowing is useful in avoiding uneven plant stands, improving tillering, reducing crop lodging, and decreasing the competition among plants as well as increasing crop productivity (Figure 3) (Hunt, 1999). According to Hundera et al. (2001), row sowing of tef with a low seed rate can reduce the problem of lodging on tef. Similarly, significantly higher grain yield was reported from row sown tef in Southern Ethiopia (Abebe and Werkayehu, 2015). On the contrary, the study by Jemberu and Gebremeskel and Embaye Habtamu Gebretsadik (2017) in the North Gondar indicated that the broadcast method of sowing gave the maximum yield of tef than that of row sowing. Another study at Debre Zeit agricultural research center showed the yield difference between the two sowing methods (i.e., broadcasting and row planting) was not significant (Chanyalew et al., 2015). In general, proper investigation needs to be made to determine the best method of tef sowing/planting both for small-scale and large-scale farmers in terms of both improving productivity and cost-effectiveness. For small-scale farmers, in addition to the traditional and widespread broadcasting method of sowing, row planting through the opening of the lid of the bottler, recently developed hand-held planters need to be investigated under diverse systems. Similarly, for large-scale farmers, tractor-mounted planters should also be included in future investigations.

3.4. Pelleting Tef Seed and the Role in Tef Husbandry
To facilitate low sowing and even distribution of tef seeds, the Tef pelleting was formed by three institutions, namely, “Syngenta Foundation for Sustainable Agriculture, the University of Bern, and the Ethiopian Institute of Agricultural Research (EIAR)”. In the first phase, pellets with 5x, 10x, 15x, and 20x size of tef grain (in weight base) were developed and tested for several agronomic parameters including germination speed and rate, stand establishment and grain yield of the. Preliminary investigations in the controlled condition at the University of Bern and field condition at Debre Zeit Agricultural Research Center of the EIAR showed that the pelleting size of 15x provides a high rate of germination (Cannarozzi et al., 2018). In addition, this size of the pellet paves the way for the mechanical planting of tef seed using planters made for other crops.

3.5. Sowing Depth
After the seedbed is prepared either by trampling with animals or humans or in some cases without trampling, tef seeds are sown on the surface of the seedbed. This practice is exercised by all farmers in Ethiopia. This practice of sowing of tef seeds on the surface of the plot severely reduces the root anchorage to the soil. The poor anchorage of tef roots partially contributes to the high incidence of lodging reported in tef (Wu et al., 2016).
On the other hand, preliminary investigation from the Tef Pelleting Project mentioned above showed that pelleted tef seeds can be placed up to 3 cm deep into the soil without losing the germination rate and speed. This shows that pelleting tiny tef seed provided several beneficial roles in tef husbandry. Sowing pelleted tef seeds at 3 cm depth significantly reduced the average lodging index and root lodging compared to 0 and 1 cm sowing depth, possibly due to the formation of a deeper root system. The sowing depth, the average lodging index from 3 cm sowing depth, was significantly reduced (30.8%) lodging than from the 0 cm sowing depth (69.3%) (Unpublished data). To draw a conclusive result, further research will be needed combining sowing depth with different soil moisture levels, seed rate, soil type, lodging, and productivity, which could lead to advances in tef production in tef growing agro-ecologies.

3.6. Sowing Window

The calendar-based tef planting window varies from place to place. However, majority of cultivation occurs during the main rainy season (also known as Meher season). Depending on the soil type and on the onset of rainfall, tef sowing was made between July 11 and August 18 EC. At Debre Zeit Agricultural Research Center, tef sowing was made from July 11 to 16 in soils with low water-holding capacity and from July 16 to 31 in soil with high water-holding capacity. The study on heavy clay soils in North Gondar showed that a significantly high grain yield of tef was obtained on July 2 sowing compared to July 30 sowing (Jemberu et al., 2018). The former had a 45% grain yield advantage over the latter.

Sowing dates are also determined by the phenology and other properties of tef germplasm used for sowing. The three-year study at Debre Zeit and AlemTena revealed that the highest tef yield was obtained from Kora varieties planting end of July in Debre Zeit agricultural research center and first July in AlemTena on the other hand, Boset varieties gave the highest grain yield at both locations when sown in mid-July. Based on these findings, the recommended sowing dates for tef are in end July at Debre Zeit and early to the second week of July in AlemTena (Table 1; Tafes et al., 2020).

The recent climate change had obvious consequences on the growing season of crops in Ethiopia. The current trend of onset rainfall across the country shifts from first of May to end of September. This early stop of rainfall in early September coincides with tef's reproductive stage, where moisture scarcity is detrimental for further development. Moisture scarcity during the flowering and grain filling periods of many plants, especially tef, has a significant impact on yield. The length of the growing season, as well as susceptibility to certain diseases and insect pest damage, are all affected by the sowing date (Mengistu & Lemlem, 2012). A study at Adiha,

| Table 1. Mean biomass yield and grain yield of tef as influenced by planting window and cultivar interaction effects at Debre Zeit and AlemTena during the 2015 to 2017 cropping season |
|-------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Variety | Sowing date | Biomass (kg/ha) | Grain yield (kg/ha) | Biomass (kg/ha) | Grain yield (kg/ha) |
| Kora | Early-July | 0.00d | 0.00d | 9766.2a | 1595.7a |
| | Mid-July | 8444.4a | 1813.3a | 8561.1a | 1371.4bc |
| | Late-July | 8333.3a | 1698.9a | 2758.3c | 655.2d |
| Boset | Early-July | 5000.00c | 600.00d | 6107.2b | 1207.2c |
| | Mid-July | 6111.1b | 1106.7c | 8947.2a | 1499.1ab |
| | Late-July | 7666.7a | 1408.9b | 2450.0c | 517.6d |
| | LSD(0.05) | 817.22 | 228.06 | 1320.0 | 211.58 |
| | CV(%) | 15.87 | 22.45 | 25.16 | 22.69 |
a site characterized by severe terminal drought due to early cessation of rainfall and sandiness of the soil, revealed that July 22 sowing increased the grain yield by 12.5% and straw yield by 6.7% over August 2 sowing. July 22 is an early sowing date by one week for area, whereas August 2 is the sowing period of local farmers (Mengistu & Lemlem, 2012). Therefore, adjusting the cropping calendar based on the onset and cessation of the rainfall and soil moisture content is an important strategy in avoiding climate related challenges. Early cessation of rainfall in early September can also be addressed by developing early maturing tef varieties, which complete their critical growth stages before deficiency in precipitation. The National Tef Research Program has been addressing this critical issue by breeding for early maturity. Tef varieties, particularly Tseday, Simada, and Boset varieties are part of this achievement. In addition, the partnership between the National Tef Research Program and the University of Bern enabled to development and release of tef variety called Bora and Boni, which suit to areas characterized by early cessation of rainfall. Hence, in addition to readjusting the sowing dates, it is also important to introduce improved varieties suit to the specific location under stress.

3.7. Tef Seed Rate
The seed rate is the most important agronomic aspect which needs due attention. In early 1992, Ethiopian farmers generally used higher seed rates (40–50 kg/ha), compared to research recommendations (10–15 kg/ha; Bogal et al., 2018; B. Abebe & Abebe, 2016; Chanyalew et al., 2015; Dereje et al., 2018; Ketema, 1997; Lakew & Berhanu, 2019). Farmers’ seeding rates may also depend on the type of tef cultivar, soil type, cropping history, and the weed intensity of the location (Legesse et al., 1992). Sowing of high seed rates of tef leads to competition among plants for nutrients, water, and sunlight, consequently, increasing in plant height and lodging, and in turn resulted in reduced yield.

Remarkable research efforts have been made concerning seed rate and unclosed the issue so far for increasing tef yield. Some research reports significant differences between different seeding rates on grain yield (Kenea, 1997; Legesse et al., 1992; Tilahun, 1992). Later, Bogal et al. (2018), and Chanyalew et al. (2015), indicated that the highest grain yield was achieved at a lower seed rate (20 kg/ha). More recently, Lakew and Berhanu (2019) reported that tef cultivars sowed at lower seed rates gave the highest grain yield (Figure 5). Most studies indicated that tef crop that gives maximum yields under low seed rate because of higher tillering natures. Therefore, the seeding rate of tef still needs further research with the consideration of soil type, tillering capacity of the cultivars, and planting methods.

Figure 5. Tef seed rate recommendations in Ethiopia from 1992–2018: Source (Bogal et al. (2018), B. Abebe and Abebe (2016), Chanyalew et al. (2015), Dereje et al. (2018), Ketema (1997), Lakew and Berhanu (2019), and Tilahun (1992).
3.8. Fertilizers Uses

Tef adapted well to various agroecology and soil types. Nevertheless, its yield is limited by nutrient deficiencies, mainly by nitrogen (N) and phosphorus (P; Mamo et al., 2001). In addition, recent research result indicated that sulfur (S) and boron (B) are yield determinants and limit nutrients in most tef cultivation areas (Habtegebrzial & Singh, 2006; Haileselassie et al., 2011). To reduce such production constraints, many on-station and on-farm studies have been conducted on NPK rate and time of application from 1967 to 2014 and from 2015 until now on NPS, NPSB, and NPSZIB to determine the optimum rates at different locations and cropping systems. Although the levels may vary, most studies have confirmed that the fertilizer requirements of tef, which can achieve the optimum yield of 100 kg/ha DAP now replaced by NPS and 46 kg N/ha (Food and Agriculture Organization (FAO), 2006).

According to USA (1990) reported, uses of adequate fertilizers rates and improved varieties, tef yield reach up to 2.5 ton/ha on the research field but the national average yield is 1.7 tons/ha. This indicated that there is a huge yield gap between the yield obtained on the research field compared to the farmers field. However, some farmers were able to harvest grain yield between 1.8–2.0 tons/ha following improved cultural practices and optimum (DZARC (Debre Zeit Agricultural Research Center), 1988). Surprisingly, tef is taking the major share of the country’s fertilizer expenditure (Ketema, 1993). According to a 1996/97 estimate of fertilizer consumption, tef accounted for 41.3 percent of the total fertilized field area (Keno, 1999). Studies conducted by Gebretsadik et al. (2009) and Mitiku and Wolde (2008), maximum total biomass, straw yield, and grain yield by high (90 kg/ha). N fertilizer application. Balcha (2014) who studied yield and yield-related traits on tef improved by the application phosphorus fertilizer except for some tef phenology. Research reported by Habtegebrzial and Singh (2006), application of N and S nutrients increased remarkable yield, on average by 1.7 kg/ha, compared with the control plots and also improved the fertilizer efficiency by 36%.

Recently, tef grain yield increase was obtained by the application of macro-and micronutrients in most tef growing areas. Studies conducted by Fekadu and Mosissa and Taye (2019) the application of blended fertilizers (NPKSznB) and 145 kg/ha urea to dressed grain yield of tef was significantly increased compared to the untreated plot. Mulgeta and Shiferaw (2017) also reported that the application of 150 kg NPS and 34.5 kg N/ha was improve tef yield. In general, tef yield response to blended and N fertilizer varies across locations based on soil fertility status, previous cropping history, and moisture conditions. Overall, fertilizer studies conducted in the past in different areas of a country, many of which were not site specific. Therefore, further investigation will needed, particularly on soil analysis on limiting macro and micro nutrients, the rate, type and time of fertilizers application and its impact on economic and biomass yield across various agro-ecologies, cropping systems and moisture conditions.

3.9. Nitrogen Fertilizer Application Time

According to Gebremeske and Embaye Habtamu Gebretsadik (2017) and Peter et al. (2019) reports, application time of N is important to maximize yield and productivity. Kidu et al. (2016) suggested that economical high yield was obtained when N applied 25% at planting and 75% at tillering but full dose application at emergence resulted in yield loss. Recently, Tafes et al. (2020) suggested that the application of ⅜ at planting, ½ at tillering, and ⅜ at heading improved grain and biomass yield of tef. Tsadik Tadele (2019) reported that N application remarkably increases yield as compared with full-dose application. However, nitrogen use efficiency of tef is quite low on average 10.8 kg/kg as compared to wheat the nitrogen use efficiency reached 33 kg/kg (Raun & Johnson, 1999). Tadele (2019) reported that increasing the fertilizer rate, resulted in decrease in apparent nitrogen recovery and nitrogen use efficiency (Figure 6). Traditional fertilizer application methods were not take into account the variability among fields and soils resulting in low fertilizer use efficiency (Butchee et al., 2011). Therefore, there is a need to overweight new approaches to improve their management strategies and mining fertilizer costs.
4. Tef Cropping System
The major concern in the agricultural sub sector in the world particularly in populace country like Ethiopia, was to increase production and productivity of crops from the existing farming system. Crop intensification has a major potential for nutritional, income, and sustainability outcomes for smallholder farming systems. Tef is mostly produced as a mono-crop, but rarely practiced in multiple cropping systems (Worku, 2020). Tef-pulse crop rotation system is the most adopted cropping system in the country but other cropping system like, intercropping, relay cropping, and double-cropping of tef with different crops were also practiced by smallholder farmers (Hundera et al., 2001).

4.1. Intercropping
Integration of legumes and cereals is a historical tradition followed by most smallholder farmers in northern Ethiopia, and it has been acknowledged as one of the most sustainable intensification strategies in smallholder agriculture. Intercropping of tef with sesame, tef with safflower, tef with sorghum, tef with gomenzer (Brassica carinata), and tef with sunflower has been practiced in different area of the country (Geleta et al., 2002; Molla & Muhie, 2011). According to Molla and Muhie (2011), tef with sesame intercropping covered 95 percent of tef-based farming in the east of Jemma river, tef with safflower intercropping, and sole tef, while in the west of the Jemma river, tef with sesame intercrops covered almost all tef cropping areas. Soil type can influence component choices of intercropped crops. On well-drained light soils and stony light soils, for example, sesame has been commonly intercropped with tef, but tef with safflower intercropping has been the dominant practice on heavy black soils or deep fertile soils. Most earlier research, on the other hand, concentrated on intercropping systems involving two-crop associations regardless of growing conditions. Growing two pulse components sequentially under intercropping instead of one could permit fully utilizing the growing season. Therefore, research on intercropping of crops with different root depth such as tef (short root) and sorghum (deep root) should be studied with regard to soil moisture uses, yield and soil fertility.

4.2. Mixed Cropping
In Ethiopia, the mixed cropping system of tef with different crops is also commonly practiced by smallholder farmers. According to Agegnehu et al. (2006) faba bean mixed and tef cropping with a ratio of 100:12.5 tef/faba bean resulted increase in grain yield (1362 kg/ha) and land equivalent ratio compared to the sole tef cropping (1480 kg/ha). However, the lowest tef grain yield (912 kg/ha) was recorded from highest (100:62.5) (tef/faba bean) proportion. Similarly, Bayu et al. (2007) reported mixed cropping of tef with sunflower improved tef yields because of their complementary
advantage rather than competitive resources use. Wondimu and his co-workers reported that, 10–50 present of sunflower gave 20–30 yield advantages in North Wollo Zone.

4.3. Relay Intercropped
Tef-maize relay intercropping practices are mostly adopted in the Sidama region in the southern part of Ethiopia. Maize has sown by hand drilling in April–May when the rain season started. When the maize reached the dough stage, the land is prepared for shallow cultivation and tef is planted by broadcasting under the standing of maize. This practice is more effective when the expected maize yield is reduced by adverse environmental conditions and drought (Worku, 2004). The same author studied the effect of maize planting patterns on tef yield under maize-tef relay cropping. The results showed that the highest tef yield (1780 kg/ha) was obtained under wider inter-row spacing (100 cm x 22.5 cm) of maize compared to narrow inter-row spacing (60 cm x 37.5 cm) and tef grain yield of 1555 kg/ha and 1554 kg/ha, respectively.

4.4. Tef Based Rotation
Farmers in north-western, central highland, and central Rift Valley parts of Ethiopia mostly rotated tef with leguminous crops such as fava bean, chickpea, lentils and common bean (Beyene & Yirga, 1989; Halil & Ketema, 2001; Z. Tadele, 1994). In some part of the country, tef is also rotated with Niger (Guizotia abyssinica (L.) f) and maize (Tolera et al., 2005). Tef productivity differed with the type of crop used for rotation, on average 3000 kg/ha, 2625 kg/ha, 2230 kg/ha, and 1700–2000 kg/ha were obtained from a crop rotated by onion, common bean, chicken, and lentils, respectively (Gizaw et al., 2018). Worku and Skjelvag (2006) conducted a two-year study on two locations, Melkassa and Wolenchiti, and the results showed an remarkable increase in tef grain yield (1231 kg/ha) of tef rotation with maize compared to the continuous tef monoculture (851 kg/ha).

5. Tef Agronomic Research Strategy for the Future out Look

5.1. Development of a Sustainable tef Cropping System
Tef production occurs within a range of different systems in the country that spans the intensive rain-fed pulse-tef, pulse-tef-tef, and/or wheat, barely, maize-tef systems in the tef growing area (Ferede et al., 2020). Despite the different cropping systems, cereal-legume rotations (with the rotation benefits of diversification, disease management, nitrogen fixation, and soil health) are currently at risk in Ethiopia (A. Abraham, 2019; Bedasa, 2018; Mitiku, 2017). Significant agriculture research in farming systems is implemented in many countries of the world. Innovations such as intensification of legumes and oilseed, minimum tillage, dual-purpose cropping system, improved soil health, integrated disease, pest, and weed management strategies were utilized in the world (Beres et al., 2020). Therefore, (i) develop diverse tef cropping systems for improved water and nutrient use efficiency to stabilize and enhance crop production through appropriate choice of crops and agronomic practices in different agro-ecological regions; (ii) Develop sustainable pest (insects, diseases, weeds) management systems that maintain soil health.

5.2. Use of Advanced Crop Management Strategies in the Face of Climate Change
Several crop management issues were reviewed in tef systems, including the alignment of tef sowing dates to changing seasonal patterns. Currently, there is a variability and change of rainfall patterns in most regions of the country where it starts in May to June and offsets early to mid-September (Murphy, 2014; USAID, 2015). Recent research reports suggest to adjust the sowing date of tef based on the length of the growing period is vital to adapt the crop to escape terminal drought (Tafes et al., 2020). However, validation trails may be needed to establish proper climate-based sowing dates in the new intervention areas.

5.3. Reduce Tef Lodging
Tef lodging is a prevalent occurrence that contributes to the present low grain yields. Lodging mostly happened before the crop reached grain-filling period or some time it occurred after grain filling (S. H. Van et al., 2010). Lodging is the most significant yield-reducing problem in tef,
accounting for up to 35% of yield losses (Berry et al., 2004; S. H. Van et al., 2010). Certain studies associated lodging to stem characteristics (stem lodging; Würschum et al., 2017), while (S. H. Van et al. (2010) and Lakew and Berhanu (2019) correlated lodging with to shoot-root junction traits (root lodging) as major contributors to tef lodging. Moreover, high population density and excess N fertilizer application can aggravate the lodging of tef. There has recently been an increase in evidence demonstrating the positive benefits of growth regulator in mitigating the negative effects of abiotic stresses on plant growth and development, by regulating hormone levels, enzymatic and non-enzymatic antioxidants, and osmyolites (Kamran et al., 2018; Kuai et al., 2016). Plant growth regulators are synthetic chemical compounds that are applied to crops to alter certain structural processes. Previous research reported that plant growth hormone led to increased yield, increased crop tolerance/resistance to abiotic stress and improved physiological traits and reduced lodging of tef (Tesfahun & Yildiz, 2018). However, there is no research reports on the residual effects of chemicals on soil health and the succeeding crops. Thus, for the sustainable application, further investigation because the plant growth regulator is relatively immobile in soil and bound mainly by organic matter (Tesfahun & Yildiz, 2018).

5.4. Tools Supporting for Improving Tef Productivity
Technologies developed to support efforts related to genetics improvements more consistently resulted in the deployment of tools when that benefits the breeder rather than the agronomist (Beres et al., 2020). But currently, a few successful instances of tools that help farmers make better agronomic decisions on the farm have been developed. Site-specific nitrogen fertilizer recommendations and cost-savings; Akvo, Caddisfly app, and an easy-to-use smartphone tool were successful at assessing the requirements for any pre-and in-season nitrogen fertilizer applications (Golicz et al., 2019). However, these technologies were not adopted for the improvement of tef so far. As a result, we assess the effectiveness of precision agriculture and big data analytics in improving tef productivity and long-term sustainability. Utilize the yield gap evaluation as a learning and measuring tool to improve tef yields. Major emphasis is placed on evaluating the effectiveness of pictures and vegetation indices produced from ground-based techniques to forecast tef yield mid-season to improve on-farm decisions.

6. Conclusion
In this review, research results and recommendations were thoroughly examined on tef with a special emphasizes on the attributes of crop management that led to exploiting genetic potential for tef production were assessed. This review article strongly argued that most of the crop management recommendations have not reflected the current yield limiting factors and inter-weather variability occurring in due course. Similarly, many recent studies had major limitations in terms of adopting modelling approaches and reflecting the diverse agro-ecologies and dynamism of farming systems. As a result, future studies should take into account these constraints, and crop management studies should be more systematic and coordinated, embracing a greater growing area. Moreover, this means that the potential to develop and deploy decision support systems will be vital.

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References
Abebe, T., & Workayehu, T. (2015). Effect of method of sowing on yield and yield components of tef (eragrostis tef (zuc) tratto) at shebedino, Southern Ethiopia. Global Journal of Chemistry, 12(1), 37–44.
Abebe, B., & Abebe, A. (2016). Effect of seed rate on yield and yield Components of tef (eragrostis tef) trotter at shebedino, Southern Ethiopia. Journal of Natural Sciences Research, 6(21), 11–16.

Abraham, R. (2015). Achieving food security in Ethiopia by promoting productivity of future world food tef: review. Advances in Plants & Agriculture Research, 2(2), 00045. https://doi.org/10.15406/apar.2015.02.00045

Abraham, A. (2019). Emerged plant virus disease in ethiopian agriculture: causes and control options. Ethiopian Journal of Agricultural Sciences, 29(1), 39–55.

Agegnehu, G., Ghizaw, A., & Sinebo, W. (2006). Crop productivity and land-use efficiency of a teff-faba bean mixed cropping system in a tropical highland environment. In Experimental Agriculture (Vol. 42, pp. 504–504). Cambridge University Press. https://doi.org/10.1017/S0014479706003863

Alvaro, F. J., Plaza, B. D., Arrúe, J. L., Cantero, M. C., & Cantero-Martínez, C. (2014). Soil organic carbon storage in a no-tillage chronosequence under Mediterranean conditions. Plant and Soil, 376(1–2), 31–41. https://doi.org/10.1007/s11104-012-1167-x

Balcha, A. (2014). Effect of phosphorus rates and varieties on grain yield, nutrient uptake and phosphorus efficiency of tef (Eragrostis tef [Zucc.] Trotter). American Journal of Plant Sciences, 5(1), 262–267. 53035 https://dx.doi.org/10.4236/ajps.2014.53035

Bayu, W., Addisu, M., Tadesse, B., & Admassu, L. (2007). Intercropping of teff and sunflower in semi-arid areas of Welo, Ethiopia. Tropical Science, 47(1), 16–21. https://doi.org/10.1002/ts.185

Bedaso, T. (2018). Distribution and management of Fusarium wilt (Fusarium oxysporum f.sp. lentis) of lentil (Lens culinaris Medikus) in Central Highlands of Ethiopia. MSc thesis in Agriculture (Plant Pathology). Haramaya University.

Beres, B. L., Hatfield, J. L., Kirkegaard, J. A., Eigenbrode, S. D., Pan, W. L., Lolatto, R. P., Hunt, J. R., Strandhorst, S., Parker, K., Lyon, D., Ransom, J., & Wiersma, J. (2020). Toward a better understanding of genotype environment management interactions: A global wheat initiative agronomic research strategy. Frontiers in Plant Science, 11, 828. https://doi.org/10.3389/fpls.2020.00828

Bekel, T. (2009). Recent developments in tef (Ethiopia’s most important cereal and gift of the world. CIIFAD Forum Seminar, 15 November 2009, 23 pp.

Berry, J. K., Delgado, J. A., Pierce, F. J., & Khosla, R. A. J. I. V. (2004). Applying spatial analysis for precision conservation across the landscape. Journal of Soil and Water Conservation, 60(6), 363–370.

Beyene, H., & Yirga, CA. 1985. Initial result of informal survey: inewary and sendafo- Ailetu areas on Northern Shewa, Working Paper No. 10. IAR, Addis Ababa, Ethiopia.

Bogale, T., Gurumsu, S., & Yadat, E. (2018). Influence of seed rate and row spacing on growth and yield of tef [Eragrosis tef (Zucc.) Trotter]. In M. Amlaz, D. Eshetu, & A. Legesse (Eds.), Crop production management technologies proceeding of agronomy and crop phyiology research (Vols. 3–4, pp. 7–11). August 12th Zeit Research Center, EIAR.

Bogale, T. E., & Le, L. B. (2016). March, Pilot optimization and channel estimation for multiuser massive MIMO systems. In 2014 48th Annual Conference on Information Sciences and Systems (CISS) (pp. 1–6). IEEE.

Butchee, K. S., May, J., & Arnoll, B. (2011). Sensor based nitrogen management reduced nitrogen and maintained yield. Crop Management, 10(1), 1–5. https://doi.org/10.1094/CM-2011-0725-01-RS

Connarazzi, G., Chanyalew, S., Assefa, K., Bekele, A., Blösch, R., Weichert, A., Klausler, D., Plaza-Wüthrich, S., Esfeld, K., Jöst, M., Rindisbacher, A., Jifar, H., Johnson-Chadwick, V., Abate, E., Wang, W., Kamies, R., Husein, N., Kebede, W., Tolosa, K., … Tadele, Z. (2018). Technology generation to dissemination: Lessons learned from the tef improvement project. Euphytica, 214(2), 1–20. https://doi.org/10.1007/s10681-018-2115-5

Chanyalew, S., Genet, Y., Fikre, T., Assefa, M., & Assefa, K. (2015). Effect of sowing method, seed rate and sowing depth on growth performance and grain yield of tef (Eragrostis tef (Zucc.) Trotter). Ethiopian Journal of Crop Science, 4, 45–57. http://www.researchgate.net/publication/313053213

CSA (Central Statistical Agency). 2020. Agricultural Sample Survey 2019/2020, report on area and production of major crops, Addis Ababa.

Dawson, I., & Joenick, H. (2000). Underutilized plant species: The role of biotechnology. Position Paper No. 1, 27.

Deckers, P. J., Hessen, B., & Teuben, J. H. (2001). Switching a catalyst system from ethylene polymerization to ethylene trimerization with a hemilabile ancillary ligand. Angewandte Chemie International Edition, 40(13), 2516–2519. https://doi.org/10.1002/1521-3773(20001002)40:13<2516::AID-ANIE2516>3.0.CO;2-V

Dereje, G., Adisu, T., & Dimberu, A. (2018). Influence of seed rate and row spacing on growth and yield of tef (Eragrostis tef) production at assosa, benishangul-gumuz regional state, Western Ethiopia. Advances in Crop Science and Technology, 6(1), 335. https://doi.org/10.4172/2329-8863.1000335

DZARC (Debre Zeit Agricultural Research Center). 1988. Annual research report for 1987/88. Debre zeit. 147p.

DZARC (Debre Zeit Agricultural Research Center). 1989. Annual research program report, Debre zeit, Ethiopia, Debre zeit Annual research progress report for 1988/89.

Ebb, T. (1969). Tef (Eragrostis tef), the cultivation, usage and some of its known diseases and insect pests. part I. Expt. Sta. Bull. 66. Haile Sellassie I University (HSIU), College of Agriculture, Whole Grain Council. http://wholegrainscouncil.org/

Feferde, S., Agegnehu, T., Kelahawie, A., Alemu, T., & Yirga, ca. 2020. Forming systems characterization and analysis in east gojam zone implications for research and development (R&D) interventions. Research Report No. 127:978-9994-66-57-3.

Fikadu, A. A., Wedu, T. D., & Derseh, E. A. (2019). Review on Economics of Teff in Ethiopia. Open Acc Biostat Bioinform, 2(1), 0005–39. https://doi.org/10.31031/OABB.2018.02

Food and Agriculture Organization (FAO). (2006). Food aid for food security. In United Nations Viale delle Termi di Caracalla 00153, Rome, Italy.

Food and Agriculture Organization of the United Nations. 2015. FAO report, climate change and food security: risks and responses. FAO.

Gebremeskel, K., & Embaye Hobtamu Gebretdsakid, A. (2017). Determination time of nitrogen fertilizer top dressing for tef grown on vertisols in the northern part of Ethiopia. Journal of Natural Sciences Research, 7(1), 70–79.

Gebremeskele, K., Embaye, A., & Gebretdsakid, H. (2016). Determination time of N fertilizer top dressing for tef growth on Vertisol in Norther part of Ethiopia. Journal of Natural Science Research, 6(1), 70–79.
Mitiku, A., & Wolde, M. (2008). Effect of faba bean (Vicia Faba L.) varieties on yield attributeus sinana and agaro districts of bale zone, Southeastern Ethiopia. *Jordan Journal of Biological Sciences*, 147(3388), 1–7. https://doi.org/10.12816/0027064

Mitiku, M. (2017). Management of root rot diseases of cool season food legumes in Ethiopia. *Journal of Plant Sciences*, 5, 104–109. https://doi.org/10.11648/j.jsps.201705d.01.12

Mollo, A., & Muhie, K. (2011). Tef (Eragrostis tef) based cropping systems in the hot to warm moist valleys of North Shewa, Ethiopia. *Scientific Research and Essays*, 6(14), 1411–1416. https://doi.org/10.5897/SRE09.090

Mossisa, F., & Taye, G. (2019). Effect of blended fertilizer formulas on tef (Eragrostis tef (Zucc.) trotter) yield and soil chemical properties on acidic soils under limited conditions at Nedjo, Western Ethiopia. *Journal of Natural Sciences*, 9(1), 1–8. https://doi.org/10.7176/JNS/9-1.01

Mulugeto, & Boken, S. (2017). Influences of balanced nutrients on the growth performance and yield of tef (Eragrostis tef(Zucc)) the midland of Benso Southern Ethiopia. *Journal of Scientific and Innovation Research*, 6(3), 101–103.

Murphy, C.A. 2016. Observed and projected climate change in the Philippines, Honduras, Kenya, Malawi and Ethiopia. Department of Geography, Maynooth University and Mavuto Tembo, Mzuzu University, Malawi. http://bit.ly/2id29YL

Peter, O., Aula, L., Oyebiyi, F., & Raun, W. R. (2019). World cereal nitrogen use efficiency trends: review and current assessment. *AgroSystems, Geosciences & Environment*, 2(1), 180065. 10.2134/age2018.10.0045.13

Raun, W. R., & Johnson, G. V. (1999). Improving nitrogen use efficiency for cereal production. *Agronomy Journal*, 91(3), 357–363. https://doi.org/10.2134/agronj1999.00021962009100030001x

S. H. Van, D., Vos, J., Ennos, A. R., & Stomph, T. J. (2010). Analysing lodging of the panicle bearing cereal tef (Eragrostis tef). *New Phytologist*, 186(3), 696–707. https://doi.org/10.1111/j.1469-8137.2010.03224.x

Schlipt-van Ettekoven, C., Giller, K. E., & Thijssen, M., 2017. N: Africa putting nitrogen fixation to work for smallholder farmers in Africa, podcaster no. 47, August and September 2017 [PhD Student]. Special (No. 47). N: Africa project.

Seyoum, E. (2001). The synergistic effects of Metarhizium anisopliae (Metischkoff) with the acyl urea insecticides tef lubenzuron and diflubenzuron for Schistocerca gregaria (Orthoptera: Acrididae). *SINET: Ethiopian Journal of Science*, 24(1), 113–125. https://doi.org/10.4314/sinet.v24i1.18179

Shiferaw, B., & Baker, D. A. (1996). An evaluation of daylight screening techniques for Eragrostis tef. *Tropical Science(United Kingdom)*.

Spaenij-Dekking, L., Kooy-Winkelklo, Y., & Koning, F. (2005). The Ethiopian cereal tef in celiac disease. *New England Journal of Medicine*, 353(16), 1748–1749. https://doi.org/10.1056/NEJMoa051492

Tadele, Z. (1996). Tef in the farming systems of the Ada area. In *Ethiopian Agricultural Research Organization (EARO)*, research report (Vol. 24). Addis Ababa: IAR.

Tadele, Z., & Assef, K. (2012). Increasing food production in Africa by boosting the productivity of under studied crops. *Agronomy*, 2(4), 240–283. https://doi.org/10.1390/agronomy2004240

Tadele, Z. (2016). Role of crop research and development in food security of Africa. *International Journal of Plant Biology and Research*, 2(3), 1019. https://doi.org/10.7892/boaris.69524

Tadele, T. (2019). Nitrogen use efficiency of tef (Eragrostis tef (Zucc.) Trotter) as affected by nitrogen fertilizer under chickpea-tef rotation at Tattaqay Koraro District, North Ethiopia. *Journal of Soil Science and Environmental Management*, 10(4), 58–67. https://doi.org/10.5897/JJSEM2017.0660

Todesse, E. (1969). Tef (Eragrostis tef): The cultivation , usage and some of the known diseases and insect pest. *Part One Debre Zeit Agricultural Experiment Stations Bulletin*, 60, 181–189.

Tafes, B., Gezahgn, A., Eshetu, S., & Tezema. (2020). Planting time effects on the productivity of tef (Eragrostis tef (Zucc.) varieties in Ethiopia. *American Journal of Life Sciences*, 8(3), 34–40. https://doi.org/10.11648/j.ajs.20200803.11

Temene, L., Amede, T., Kihoro, J., Tibebe, D., & Schulz, S. (2017). A review of soil fertility management and crop response to fertilizer application in Ethiopia: towards development of site- context specific fertilizer recommendation. CIAT publication no. 443. Addis Ababa. p.86. http://hdl.handle.net/10568/82996

Tari, J. J., Molina, J. F., & Castejon, J. L. (2007). The relationship between quality management practices and their effects on quality outcomes. *European Journal of Operational Research*, 183(2), 483–501. https://doi.org/10.1016/j.ejor.2006.10.016

Temesgen, M. 2007. Conservation tillage systems and water productivity implication for smallholder farmers in semi-arid Ethiopia. Doctoral thesis, Delft University of Technology and of the Academic Board of the UNESCO-IHE, Institute for Water Education, Delft the Netherlands. SG2000. 2002. Sasakawa Global 2000, Proceedings of the Workshop on Conservation Tillage, April 4, 2002, pp 48–49.

Tesfahun, W., & Yildiz, F. (2019). Response of crops to paclobutrazol application: A review on. *Cogent Food & Agriculture*, 4(1), 1525169. https://doi.org/10.1080/23311932.2022.2083539

Tesfahun, W., & Yildiz, F. (2019). Response of crops to paclobutrazol application: A review on. *Cogent Food & Agriculture*, 4(1), 1525169.

Tesfahun, W., & Yildiz, F. (2018). Response of crops to paclobutrazol application: A review on. *Cogent Food & Agriculture*, 4(1), 1525169.

Tefsafan, W., & Yildiz, F. (2018). Response of crops to paclobutrazol application: A review on. *Cogent Food & Agriculture*, 4(1), 1525169.

Tefsafan, W., & Yildiz, F. (2018). Response of crops to paclobutrazol application: A review on. *Cogent Food & Agriculture*, 4(1), 1525169.

Tefsafan, W., & Yildiz, F. (2018). Response of crops to paclobutrazol application: A review on. *Cogent Food & Agriculture*, 4(1), 1525169.

Tefsafan, W., & Yildiz, F. (2018). Response of crops to paclobutrazol application: A review on. *Cogent Food & Agriculture*, 4(1), 1525169.
Worku, W., & Skjelvag, A. O. (2006). The effect of different moisture and light regimes on productivity, light interception and use efficiency of common bean. *SINET: Ethiopian Journal of Science*, 29(2), 95–106. https://doi.org/10.4314/sinet.v29i2.18266

Worku, W. (2020). Performance, radiation capture and use by maize–mungbean–common bean sequential intercropping under different leaf removal and row orientation schemes. *Experimental Agriculture*, 56(5), 752–766. https://doi.org/10.1017/S0014479720000307

Wu, W., Ma, B. L., Parianti, P., Landi, S., Tonazzini, I., Cecchini, M., Piazza, V., & Gemmi, M. (2016). A new method for assessing plant lodging and the impact of management options on lodging in canola crop production. *Scientific Reports*, 6(1), 1–17. https://doi.org/10.1038/s41598-016-0001-8

Würschum, T., Langer, S. M., Longin, C. F. H., Tucker, M. R., & Leiser, W. L. (2017). A modern green revolution gene for reduced height in wheat. *The Plant Journal*, 92(5), 892–903. https://doi.org/10.1111/tpj.13726