Yield Effects of Plot-Level Korra Tef (Eragrostis tef) Seed Rate in Central Ethiopia: Application of the Dose-Response Model

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Abstract

Ethiopia's government and development practitioners have encouraged the utilization of improved *tef* (*Eragrostis tef*) varieties to increase crop production. However, apart from introducing improved *tef v*arieties, more needs to be known about the plot-level yield effects of adopting these varieties. Based on this, the current study sought to investigate the yield effects of plot-level *tef* seed rate in Central Ethiopia, focusing on the *Korra tef* variety. Two Hundred Twenty One (221) *Korra tef* producers were selected using multi-stage stratified sampling technique. Survey data were gathered from these respondents using a questionnaire, and interview guides were used to gather qualitative data from the key informants. The yield outcomes of seed rate users categorized as users below, within, and above the recommendations were examined using one-way ANOVA. The F-test results indicated disparities in yield across the three types of seed rate users. The impacts of seed rate on yield were examined using the Dose-Response Model, which was applied to five seeding rates (12, 14, 16, 18, and 20kgha^{-1}). According to a Dose-Response analysis, the highest average tef yield was attributed to a seed rate of 20 kgha^{-1}, slightly higher than recommended. The findings revealed a significant correlation between the utilization of the recommended *Korra* seed rate and increased crop productivity among growers. It is evident that encouraging farmers to solely use improved seed varieties is insufficient. Rather, the focus should be on promoting the utilization of the recommended seed rates. Furthermore, a reassessment of the ideal *Korra tef* seed rate for the study area is warranted, considering the

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observed benefits in productivity as farmers approached the utilization of the recommended rate.

Keywords: *Korra tef,* plot-level seed rate, yield, One-way ANOVA, dose-response function, Central Ethiopia

1. Introduction

Tef, Eragrostis tef, is a staple food crop for 70% of Ethiopians and is currently used in several countries to produce grain and fodder (Numan et al. 2021). It is suited to various habitats, including those with wet soil and drought stress (Assefa et al. 2015). It is growing in popularity in developed countries' healthy food markets because of its appealing nutritional composition and gluten-free accreditation (Aemiro et al. 2021). In addition to being a good source of iron and fiber, it also contains more calcium and other essential minerals than other grains (Koubová et al. 2018). Despite the preferences, and occupying the largest area of all grain crops (24%, or 3.02 million hectares) and the second-highest grain production in Ethiopia (17.29% or 5.02 million tons), its national average yield is relatively poor compared to other cereals. In 2015-16, it had a national average yield of 15.6 quintals per hectare, significantly lower than the same year's average national output for maize (33.87 quintals per hectare) (CSA 2016).

The types of seed and soil, waterlogging, insect pests, and weeds are some factors that significantly impact grain output. Agronomic factors like seeding rate and methods, seedbed preparation, fertilizer rate, and application timing continue to significantly impact the yield of *tef* (Amare and Adane 2015; Dargicho et al. 2020; Tulema et al. 2005). Seeding rates and sowing techniques significantly impact the *tef* produced and its yield (Yechale et al. 2021). The lack of reliable data on the responses of several high-yielding varieties is also stated as one of the main challenges to sustainable *tef* production (Mebratu et al. 2016). Thus, knowing the effects of a seed rate enables one to make an informed choice regarding its use.

Most farmers in developing countries use either lower or higher seed rates than the recommended ones, which widens the gap between potential and actual yield (Yirgalem et al. 2021). Likewise, *tef* seeding rates in Ethiopia vary depending on the seed used and the farmers' practices. Due to the small seed size (1000 seeds weigh just 0.265 grams), it would be challenging to spread 15 $kgha^{-1}$ of seeds evenly if the sowing method is via broadcasting. Other than these, it is worth mentioning that introducing agencies, programs, or institutions have established their own seed rate standards when introducing new varieties of *tef*. As an example, for the *Korra tef* variety the second phase of the Agricultural Growth Program (AGP II) has recommended a seed rate ranging from 15 to 18 kilograms per hectare ($kgha^{-1}$), based on information gathered from Key informant interviews conducted on October 11, 22, and 28, 2020. These specific seed rate guidelines provide valuable insights into the recommended quantity of seeds to be used per hectare for optimal *Korra tef* cultivation under the AGP II initiative.

Low seed rates result in fewer plants per unit area, reducing production; high seed rates promote competition among crops for scarce resources like water, nutrients, and sunlight, leading to poor crop quality and low yield (Hameed et al. 2002). Plants compete fiercely for a light above ground and nutrients below ground when their density surpasses an ideal threshold (Baloch et al. 2002). The consequence is a slowdown in plant growth and a reduction in grain output. These facts suggest the necessity of calculating the optimum plant population density per unit area to achieve the highest yields.

Numerous studies (e.g, Amare & Adane, 2015; Bekalu and Arega, 2016; Arega and Yemgnushal, 2018; Abraham et al., 2018; Getahun et al., 2018; Abraha et al., 2020; Yechale et al., 2021; and Wolde, 2021) have been carried out in various settings on the yield response of *tef* to its seed rates. These studies indicated how using the appropriate seed rates increased *tef* yields significantly and hinted that regulating the seed rate could greatly impact *tef* yields. However, a detailed study has yet to be conducted into how different *tef* varieties respond to seed rates. There also needs to be more information on Ethiopia's recommended *tef* seed rates in general and the *Korra tef* variety in particular. Location-specific seed rate trials and validations is also strongly advised to maximize production (Yirgalem et al., 2021). However, the yield impact of farm-level *Korra tef* seed rates in the study area has yet to be discovered. As a result, this study aims to investigate the productivity effects of *Korra tef* seed rates and examine the correlation between plot-level seed rates and yield in Central Ethiopia. Currently, there is a lack of consistent and reliable recommendations for growing *tef*, and there are notable variations in the existing advice. This study aims to bridge this gap by providing insights into the best seed rate for producing *Korra tef* using the broadcasting method. In simpler terms, the research intends to determine how much seed should be used to achieve optimal *Korra tef* production. It is important to note that additional field experiments will be required to validate and improve these findings. Nonetheless, the outcomes of this study will be a valuable initial reference for future agronomic research in this field.

This study is expected to make two contributions to the literature. First, the common metric to measure crop yield per hectare in response to a certain seed rate is the General Linear Model (GLM) (Bekalu and Arega, 2016; Arega and Yemgnushal, 2018; Abraham et al. 2018), while others use average treatment effect models (Amare and Adane, 2015; Abraha et al. 2020; Getahun et al. 2018). However, this study has come with an unusual analytical approach, the dose-response model, a popular analytical model in medical science disciplines (Ritz et al. 2015; Van der Vliet and Ritz 2013). Hence, according to the researchers, this study is the first of its kind in the study area to utilize a generalized linear dose-response model to investigate the effects of plot-level *tef* seed rates on its yield, making it a novel contribution to the existing body of research. While there have been recent studies applying this model in other crops, the specific application of this model to *tef* in this study sets it apart and offers unique insights into *tef* cultivation. Second, it will contribute to empirical research on the issues of plot-level seed rates vis-à-vis their yield and assist farmers in determining whether to alter the suggested seed rates.

1.1. Conceptual Framework

The conceptual framework for the study, shown in Figure 1, builds upon previous theoretical, conceptual, and empirical literature. The framework aims to examine the effect of plot-level *Korra tef* seed rate on the yield of farm households who have used the crop in the study area, taking into consideration various demographic, socio-economic, and institutional factors that are characteristics of grower farm households.

The central focus of the framework is the treatment variable, which is the seeding rate ranging from 12 to 20 $kgha^{-1}$. This range is based on observations of seed rates applied by the farmers under study. It represents the minimum and maximum seeding rates used by farmers in the study area. The study's dependent variable, the average yield of *Korra tef* produced by farm households, is situated on the far right of the framework. On the extreme left, the framework includes demographic, socio-economic, and institutional factors that are assumed to be unaffected by interventions other than the adoption of the *Korra tef* variety. These factors are selected based on their relevance to the study and their potential influence on yield outcomes.

The conceptualization is grounded in the understanding that the AGP II introduced the *Korra tef* variety to improve yield for farm households in the study area. Additionally, AGP II recommended a specific seed rate to enhance the yield of the introduced seed. Therefore, the framework aims to evaluate how the plot-level *Korra tef* seed rate, within the observed range, affects the yield of farmers who have adopted the crop.

With these, the framework serves as a roadmap for the overall examination of the study. It incorporates relevant theoretical, conceptual, and empirical literature to illustrate the relationship between seed rate and yield, considering the specific contextual factors associated with grower farm households. The framework provides a clear understanding of how the utilization of *Korra tef* seed at the recommended dosage is expected to enhance crop yields when other factors are held constant.

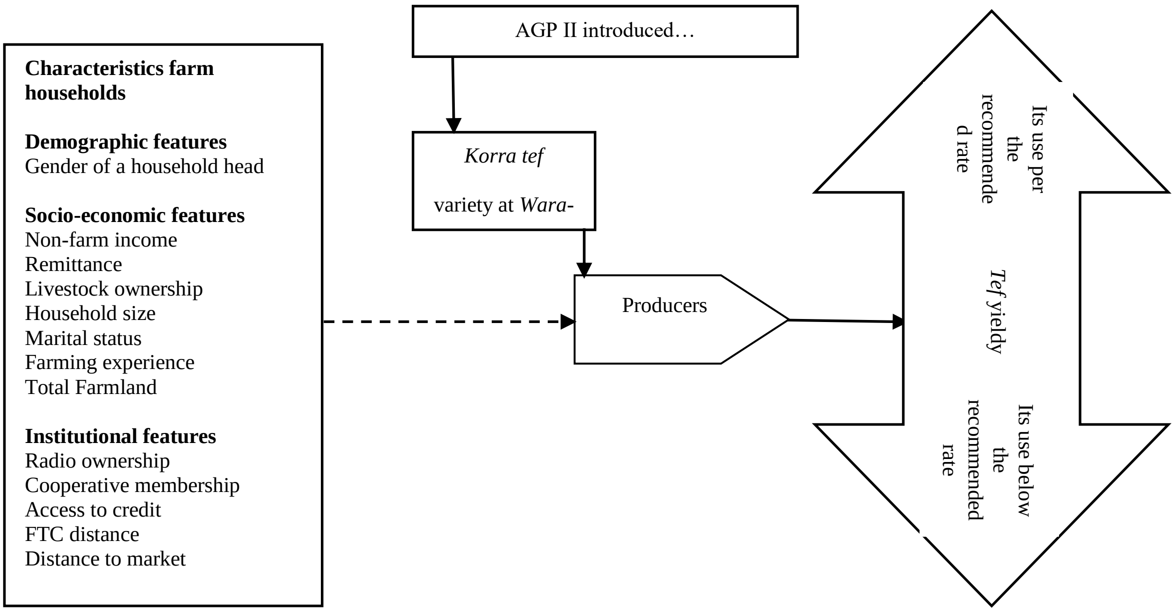

Figure 1. Yield effects of plot-level *Korra tef* seed rate
Source: Authors' construction

2. Materials and Methods

2.1. Description of the study area

Wara-Jarso[1]*Woreda* is located in the *Oromia* region, Central Ethiopia. It is found 185 km from Addis Ababa, the country's capital city. It is located at 38° 14' 60.00" East longitude and 9° 49' 59.99" North latitude. Highland (7.3%), temperate (43.4%), and lowland (49.5%) are the three main agro-ecologies (National Meteorological Agency of Ethiopia [NMAE] 2020). The majority of farmers in the area work under the mixed agricultural method. *Tef*, wheat, maize, and sorghum are the major cereal crops farmed in the *woreda*. The study area's map is shown in Figure 2.

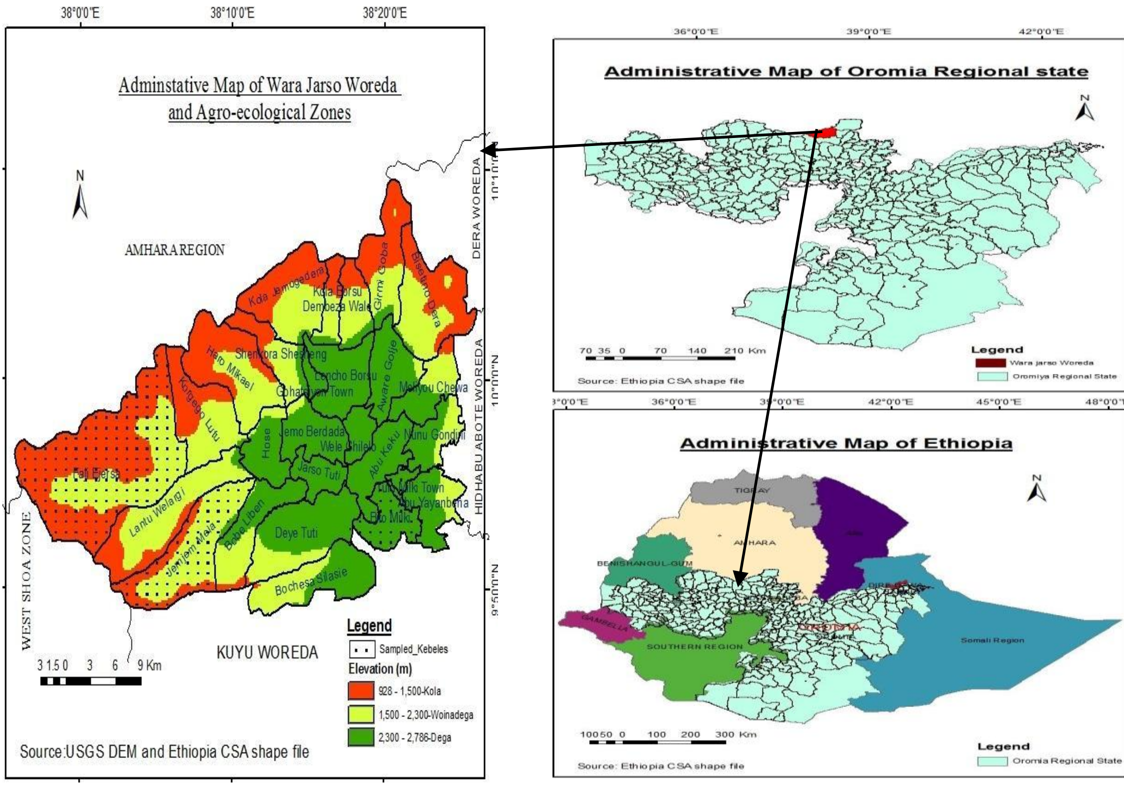

Figure 2. Location map of the study area, *Wara-Jarso woreda*, Oromia Region
Source: Ethio GIS and CSA (2007)

2.2. Context of the study

The study area is characterized by widespread cultivation of *tef*, making it the foremost crop in the area, with production taking place across various agro-climatic zones. In line with the objective of enhancing crop yields, AGP II introduced the *Korra* variety of *tef* to this particular area. This choice was driven by the area's notable potential for *tef* production. The selected *tef* cultivar, *Korra*, exhibits a higher production capacity compared to other varieties. Farm households were specifically chosen for utilization based on several criteria, including their willingness to cultivate *Korra tef* on a minimum of one hectare, their openness to engaging with local development agencies, and their preparedness to adopt the recommended farming practices.

The researchers highlight that the introduction of the *Korra tef* variety holds significant promise in enhancing crop productivity and fostering the overall agricultural development of the area. Recognizing its potential impact, they have identified *Korra tef* as a suitable pathway to accomplish the desired yield improvements. By leveraging the unique traits and characteristics of *Korra tef*, the researchers anticipate tangible benefits in terms of increased crop yields, thereby contributing to the advancement of agricultural practices in the area.

2.3. Research design and ethical procedures

The Concurrent Embedded Strategy of the mixed method was used as the study's research design. Based on this strategy, the survey data were used as the method's guiding primary data, and the qualitative data were blended within the survey data. The Center for Rural Development Studies at Addis Ababa University provided ethical permission and clearance to satisfy the ethics requirements for scientific study. Based on this, the general purpose of the study, the freedom to choose whether or not to participate in it without experiencing any negative consequences or effects, the lengths of the study, and the right to discontinue at any time were all carefully laid out for the study participants so that they could feel free to choose whether or not to take part. Additionally, they were made aware that any information they provided would be treated in the strictest secrecy, that only aggregate data would be released, and that responses would not be connected to specific participants. The study typically began after providing the above explanations and obtaining the participants' verbal and written consent for the interviews and survey.

2.4. Sampling technique and sample size determination

A multi-stage sampling technique was employed to select sample households from the *Korra tef* producer smallholders, the study's target population. The selection of *Wara-Jarso woreda* as the study area was intentional, primarily because *tef* serves as the predominant staple food crop in this area. It holds the top position in terms of its contribution to overall grain output and market share, with wheat following as the second most significant crop. In addition to being consumed locally, *tef* also plays a vital role as a cash crop, animal feed, and even as a construction material, as reported by the Wara Jarso woreda Agriculture and Natural Resource Office (2019). This highlights the multifaceted importance and versatile uses of *tef* within the local community. In the second stage, the selection process involved choosing two [2]*Kebeles* from each of the three agro-ecological zones, namely Highland, Temperate, and Lowland. This selection was based on the designated categories of high and medium *Korra tef* growers, ensuring that the samples obtained were representative of the target population.

These categories were established to enhance the representativeness and generalizability of the study's findings. The classification of high and medium *Korra tef* growers was determined by considering the existing status of *Korra tef* production, as informed by key stakeholders in the study area, including DAs and the AGP II coordinator. Finally, considering the factors of agro-ecological zone and the classification of high and medium *Korra tef* production, a total of six rural *kebeles* were included in this study. The program's beneficiary farm households were believed to share similarities since the same selection criteria were used throughout the intervention *woreda*'s agro-ecological zones. The sufficiency and representativeness of the selected samples are guaranteed by such homogeneity. The *Korra tef* growers' lists were obtained from the study *kebeles*' official documents. Finally, at the 95% desired level of precision, a total of 221 farm households were considered by (Yamane 1967) sample size determination formula considering the finite nature of the population under study.

$$n = \frac{N}{1 + N\,(e^2)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .. [1]$$

Where n = is the required sample size,

N = is the population size (7400 farming households – see Table 1 for the figure) and

e = is an acceptable margin of error (or the desired level of precision), which is 0.05.

The sample sizes in each *kebele* were determined using Probability Proportional to Size (PPS) of the farm households considered for the study (see Table 1).

Table 1. Distribution of population and sample households across the study kebeles

Respondent type	Kebeles	Population size	Sampled households
Korra tef producers	Lencho Borsu	1100	70
	Wale Chilalo	540	35
	Abo Yayambana	510	33
	Dhaye Tuti	600	39
	Jemjem Mela	370	24
	Faji Ejersa	305	20
	Total	**3425**	**221**

Source: Computed from own field survey (2020)

2.5. Data collection

The leading primary data (*i.e.* quantitative data) was collected from *Korra tef* grower farm households in September and October 2020. Trained enumerators used hard copies of semi-structured questionnaires to gather the data. It is important to note that although the data collection occurred during those specific months, the information obtained pertained to the respondents' previous harvesting season. The interviews were conducted in *Afan Oromo* after the questionnaire was initially written in English. A pilot test was conducted to evaluate the tool's validity and reliability. AGP II coordinator, zonal AGP II facilitator, regional AGP II monitoring and evaluation officer, one DA from each agro-ecology zone, and six *Korra tef* producer farmers (two farmers from each agro-ecology labelled as high and medium producers) served as the study's key informants and provided the supportive qualitative data. The study's lead researcher used the interview guides to gather it. The official reports of the study *woreda*'s AGP II coordination office, pertinent journal articles, thesis, dissertations, books, proceedings, websites, and other sources were also reviewed to generate secondary data, which was then used to complement the primary data obtained from the primary sources.

2.6. Data analysis

To analyze the quantitative data, we employed a combination of descriptive statistics and econometric analysis. This comprehensive approach allowed us to gain a detailed understanding of the data from multiple angles and uncover meaningful insights. Descriptive statistics provided us with a summary of the key characteristics and trends within the dataset. By examining measures such as means, standard deviations, and frequencies, we were able to describe and summarize the quantitative data in a clear and concise manner. Furthermore, econometric analysis was employed to delve deeper into the relationships and patterns within the data. This rigorous statistical technique enabled us to explore the potential causal relationships among the study variables.

For the qualitative data analysis, we employed text interpretation, specifically thematic coding, as our chosen method. This approach allowed us to integrate and synthesize various relevant aspects of the study, enabling us to develop a comprehensive understanding of the subject at hand. By employing thematic analysis, we aimed to identify and explore recurring themes or patterns within the data that held significance to the research question. To accomplish this, we initially conducted open coding, organizing segments of the raw qualitative data that conveyed ideas aligned with our study objectives. This process facilitated the systematic arrangement of information and the identification of key themes emerging from the data. To enrich our analysis, the organized transcripts of the qualitative data obtained from the KIIs were integrated with the quantitative data. This fusion of data sources provided valuable context and aided us in interpreting the quantitative findings.

Overall, the combined utilization of thematic coding and the integration of qualitative and quantitative data enhanced our understanding of the research topic, enabling us to draw comprehensive insights and meaningful conclusions.

2.6.1. Tools and techniques of descriptive data analysis

The respondents' demographic, socio-economic, and institutional traits were described using means, standard deviations, proportions, frequencies, and percentages. Analysis of variance (ANOVA) was used in the light of (Amare and Adane, 2015; Getahun et al. 2018; Dargicho et al. 2020; Yechale et al. 2021; Abraham et al. 2018) to examine the nature and degree of the correlation between yield and seed rates. Thanks to one-way ANOVA, we could divide the seed users into more than two groups, including those who were recommended and those who were below and beyond recommendations. Such categorization enables us to demonstrate yield disparities between the various seed rate user categories.

2.6.2. Specification of dose-response model

The dose-response model is employed to establish a cause-and-effect relationship (Guardabascio and Ventura, 2014; Robinson et al. 2020). This model relates the independent variable, dose or concentration, to the dependent variable, response or effects. In this context, the dose refers to a predetermined quantity of biological, chemical, or radiation stress that elicits a specific known response (Ritz et al. 2015). It is important to note that while the assumption of non-negativity is often valid in intended experiments, it may not always hold true (Rudemo et al. 1989).

Conversely, the response is defined by the specific dose and is subject to random variation as it quantifies the relevant effect. The response can take various forms, including continuous variables such as biomass, enzyme activity, or optical density, binary variables such as dead/alive, immobile/mobile, or present/absent, or discrete variables such as the count of juveniles, offspring, or observed roots within a specific time interval. However, continuous response variables are the most common (Van der Vliet and Ritz, 2013). The terms "dose-response" and "dose-effect" are used to describe the events following exposure (Guardabascio and Ventura, 2014).

In this specific study, the response or effect is represented by the yield of *Korra tef*, while the dose or concentration refers to the rate at which the *Korra tef* seed is applied by the grower farm households. Hence, the Dose-Response Function is used to quantify the effect of seed rate on crop yield. The dose-response curve describes the extent to which the desired reaction changes as the dose varies, and it is assumed that a linear dose-response relationship exists between the yield of *Korra tef* seed (response/effect) and its rate of application (dose/concentration).

This section provides a comprehensive specification of the dose-response (regression) model, including the parametric function that characterizes the mean of the response based on the dose. The mean trends are primarily modeled using S-shaped or related biphasic functions, as these functions reflect the causal relationship between the dose and the response, such as monotonic increase or decrease towards minimum or maximum response limits (Calabrese, 2014). These functions offer flexibility and adaptability, allowing for the interpretation of observed effects within different frameworks, including parametric survival analysis, generalized (non)linear regression, and nonlinear regression (Ritz et al. 2015).

In our study, the model function f, represented as E(Y) = f(x, β), characterizes the mean of the response variable y as a function of the dose x.

$$E\ (Y) f\ (x, \beta) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots [2]$$

The observed response values y for a given dose x ≥ 0 are distributed around f(x, β). The function f is well-known and reflects the assumed relationship between x and y, except for the model parameters β = (β1, ..., βp), which need to be estimated from the data to determine the best fit. It is important to note that while y values are often positive, they can also be arbitrarily positive or negative. The assumptions regarding the distribution of y depend on the specific type of response variable.

When doses are not randomly assigned, as in the case of our study, the Generalized Propensity Score (GPS) can be utilized to estimate the dose-response function (Guardabascio and Ventura, 2014). The GPS balances the treatment level based on observable characteristics, similar to the binary propensity score. Within the same GPS strata, the treatment level can be considered random, conditional on the observable characteristics. This helps eliminate biases resulting from covariate differences (Hirano and Imbens, 2004). The balancing property of the dose-response function also aids in mitigating hidden biases by utilizing observable characteristics common to all *Korra tef* grower farm households to estimate the propensity score.

In our study, the dose-response function was estimated using the STATA command developed by Bia and Mattei (2008). This command has been widely used in the methodological literature for estimating dose-response relationships.

2.7. Definition of variables and working hypothesis

The study's treatment variable is the seeding rate (*i.e.* 12, 14, 16, 18 and 20kgha^{-1}), while the dependent variable is the average yield of *Korra tef* produced by farm households. Gender of household head (SEXHH), marital status of household head (MARSTATUSHH), farming experiences of household head (FARMEXPHH), family size of household (HHSIZE), total farmland (TOTLAND), livestock owned by household (TLU), functional radio (RADIOOWN), access to credit services (CREDUSE), distance from home to [3]FTC (FTCDIST), cooperative or association that households primarily participate in (MAINPARTCCOOP), and distance from home to the main market (to input and output market) (MRKTDIST), income from non-farm activities (INONFARMACT), and remittances, money transferred both from inside the country and abroad (REMIT) are the demographic, socio-economic, and institutional factors which are deemed to be the common characteristics of the adoptive farm households. These traits were chosen under the presumption that the grower farmers would not be significantly impacted by interventions other than the utilization of the *Korra tef* variety.

3. Results and Discussion

3.1. Descriptive results

Table 2 presents the statistical summary of the chi-square test distribution for dummy and categorical variables for users. The variables included in the table are SEXHH (gender of the household head), MARSTATUSHH (marital status of the household head), RADIOOWN (radio ownership), CREDUSE (credit usage), and MAINPARTCCOOP (participation in agricultural cooperative).

The results of the chi-square test for gender (SEXHH) showed that 89.14% of users were male-headed households, while 10.86% were female-headed households. In terms of marital status (MARSTATUSHH), the majority of users (54.52%) were married, followed by single spouses (45.48%). A small percentage of users were married to more than one spouse (1.04%), single (0.84%), divorced (1.88%), widowed (2.09%), or not living together for any reason (1.88%). Regarding radio ownership (RADIOOWN), 50.23% of users owned radios, while 49.77% did not. For credit usage (CREDUSE), 42.99% of users reported using credit, while 57.01% did not. In terms of participation in agricultural cooperatives (MAINPARTCCOOP), 66.52% of users were involved in agricultural cooperatives, while the remaining percentages were involved in other organizations such as village saving and loan associations (4.07%), RUSSACO (10.86%), *Iddir* (1.81%), *Equub* (1.36%), *Kebele* council (4.98%), Youths' association (3.62%), Women's association (0.90%), Local representative (2.71%), and Religious organization (3.17%).

These results indicate that among the users, the majority were male-headed households, married, owned radios, used credit, and were involved in agricultural cooperatives. These findings provide insights into the characteristics and patterns of users in the study population.

Table 2. Statistical summary of X^2-test distribution for dummy and categorical variables

Explanatory variables	Categories	*Korra tef* grower farmers (%)
SEXHH	Male	197 (89.14%)
	Female	24 (10.86%)
MARSTATUSHH	Married, Single Spouse	201 (45.48%)
	Married, more than one spouse	3 (60.00%)
	Single	1 (25.00%)
	Divorced	5 (55.56%)
	Widowed	9 (90.00%)
	Not together for any reason	2 (22.22%)
RADIOOWN	Yes	111 (50.23%)
	No	110 (49.77%)
CREDUSE	Yes	95 (42.99%)
	No	126 (57.01%)
MAINPARTCCOOP	Agricultural cooperative	147 (66.52%)
	Village saving and loan association	9 (4.07%)
	RUSSACO	24 (10.86%)
	Iddir	4 (1.81%)
	Equub	3 (1.36%)
	Kebele council	11 (4.98%)
	Youths' association	8 (3.62 %)
	Women's association	2 (0.90%)
	Local representative	6 (2.71%)
	Religious organization	7 (3.17%)

Source: Computed from own survey data (2020)

The t-test results in Table 3 indicated that *Korra tef* growers, on average, possess a farming experience of 18.70 years, indicating a considerable level of expertise and knowledge in agricultural practices. In terms of household size, users have an average of 7.24 members, suggesting larger familial structures. This could potentially serve as a source of both benefits and challenges, as the availability of additional family labor may contribute to reduced production costs, but it may also strain income and productivity due to increased dependents. The average total farmland for users is 1.87, indicating a substantial land allocation for agricultural activities. Moreover, users possess an average of 3.00 Tropical Livestock Units (TLU), signifying their engagement in livestock ownership. Notably, users have a relatively shorter distance to the nearest market, with an average distance of 2.32, which can facilitate easier access to market opportunities. Additionally, the average distance to the nearest Farmer Training Center (FTC) for users is 11.50, highlighting their proximity to valuable agricultural resources and knowledge hubs. Users receive an average of 1172.85 in remittances, indicating the potential influence of external financial support on their agricultural endeavors. These descriptive findings shed light on the characteristics and circumstances of users, contributing to a comprehensive understanding of their agricultural practices and household dynamics.

Table 3. Statistical summary of t-test for continuous variables

Explanatory variables	**Mean values of *Korra tef* growers**
FARMEXPHH	18.70136
HHSIZE	7.235294
TOTLAND	1.871136
TLU	3.000905
FTCDIST	2.316742
MRKTDIST	11.50362
INONFARMACT	3581.9
REMIT	1172.851

Source: Computed from own survey data (2020)

During the 2020 production season, farmers who were users of the *Korra tef* variety exhibited distinct patterns in input usage. The t-test analysis revealed that *Korra tef* growers used an average amount of 16.9 $kgha^{-1}$ of *tef* seed (Table 4). The qualitative interviews supported this finding, indicating that the *Korra tef* variety requires a lower amount of seed sowed per hectare. Users of the *Korra tef* variety also demonstrated higher utilization of other agricultural inputs compared to other tef variety growers. They surpassed others in the use of inputs such as DAP (diammonium phosphate), urea, herbicides, and insecticides. The qualitative interviews highlighted that the use of the *Korra tef* variety necessitates a higher application of fertilizers, herbicides, and pesticides compared to alternative *tef* varieties. This increased input usage among users can be attributed to the AGP II intervention and continuous awareness-raising activities that promote compliance with recommended dosages of agricultural inputs.

Table 4. Average input use for *tef* production by respondent types (kg/ha)

Input item	**Mean values of *Korra tef* growers**
Seed (*Korra tef* variety)	16.90991
DAP	93.71516
Urea	110.737
Herbicide	1.04669
Insecticide	1.093484

Source: Computed from own survey data (2020)

Regarding costs, users of the *Korra tef* variety incurred higher average costs compared others. The cost disparities extended to various inputs such as *tef* seed, DAP, urea, herbicides, and insecticides. The qualitative evidence supported these findings, indicating that improved *tef* varieties, particularly the *Korra tef* variety, require a larger financial commitment compared to local *tef* varieties (Table 5). Labor costs were also higher for users of the *Korra tef* variety. The qualitative interviews highlighted the labor-intensive nature of cultivating the *Korra tef* variety compared to other *tef* varieties. This suggests that users invest more labor in *tef* cultivation due to the specific requirements of the *Korra tef* variety.

In summary, users of the *Korra tef* variety demonstrated distinctive input usage patterns and incurred higher costs compared to other *tef* varieties. They used a lower amount of *tef* seed per hectare but utilized more fertilizers, herbicides, and pesticides. The higher costs among users reflect the financial commitment associated with improved *tef* varieties. Additionally, the cultivation of the *Korra tef* variety was characterized by higher labor requirements. These findings shed light on the characteristics and costs associated with *tef* cultivation among users of the *Korra* variety.

Table 5: Average input costs of *Korra tef* production by respondent types (ETB/ha)

Inputs	**Mean values of *Korra tef* growers**
Seed (*Korra tef* variety)	825.15
DAP	1405.73
Urea	1494.95
Soil erosion protection	39.60
Compost	1332.91
Herbicide	188.39
Insecticide	273.32
Labor	17047.50
Total production cost	23223.27

Source: Computed from own survey data (2020)

The ATA favours row planting over broadcasting and recommends reducing the seed rate for row planting to between 3 and 5kgha^{-1} to allow for less seedling competition and ideal tilling of the *tef* plant (ATA 2015). Traditionally, farmers broadcast the seed at 25-50kgha^{-1} (ATA 2013). Following the introduction of the *Korra tef* variety by the AGP II as a component of its intervention package to increase crop yield, the program's beneficiary farmers were instructed to plant it alongside other *tef* varieties at a seed rate of 15-18kgha^{-1}. Farmers in the study area chose the broadcasting method, but some disregarded the recommendation and applied their seed rates (KIIs, October 11, 22 and 28, 2020). As outlined in the methods section, the *Korra tef* grower farm households were categorized into three groups based on the recommended seed rate for the study area. This categorization aimed to assess the impact of plot-level seed rates on *tef* production. The first group comprised farmers who used less seed than the recommended rate, the second group consisted of farmers who followed the recommended seed rate, and the third group included farmers who used more seed than recommended.

The distribution of average production across different seed rates is shown in Table 6, along with the one-way ANOVA results for the farmers' use of seed rates that were below, at, and above the recommendations during the 2020 cropping season. Accordingly, the analysis of variance showed that 4.52%, 12.22% and 83.26% of the respondents use seed rates below, above, and within the recommended rates, respectively. This indicates that more than 95% of the farmers in the study area use seed rates that are above or within the recommended range. Farmers in the study area have typically used a seed rate of 16.95kgha^{-1}, which is within the recommended range. The analysis of variance showed a significant yield difference between farmers who use below, at, and above the recommended seed rates and a very significant ($P < 0.001$) effect of seed rate on grain production. Farmers that use seed rates that are lower than recommended have the lowest average *tef* yield. This finding was corroborated by the studies done by (Arega and Yemgnushal, 2018; Shifera et al. 2020), who reported that seed rates had a significant impact on grain yield. This result is also consistent with the qualitative data where the key informants reported that the AGP II had been widely engaged to change the study area's trend of using seed rates below the recommended rates. In other words, the fact that most farmers follow the recommended seed rate indicates that most program beneficiaries have followed what the relevant agricultural development experts of the study area have instructed. The outcome also aligns with the key informants' statements that some farmers deviate from the advised seed rates.

The study participants were asked about their use of seed rate. Since they used to link greater seed rates with larger yield gains, they prefer to apply higher seed rates than recommended to achieve better yield growth. However, improvements were noted once they were advised to adhere to the recommended doses by the agricultural development experts via the AGP II activities. These purported improvements have been supported by the relevant data gathered and analyzed.

Table 6. Distribution of average yield across varying seed rates

Seed rate	Observation		Seed Rate ($kgha^{-1}$)		Yield ($Qtha^{-1}$)		F (Prob > F)
	Freq.	Percent	Mean	Std. Dev	Mean	Std. Dev	
Below-recommendation (<15 $kgha^{-1}$)	10	4.52	13.85	0.8181958	1606.643	417.6449	2.46 (0.0003)
Within-recommendation (>=15 $kgha^{-1}$ & <=18 $kgha^{-1}$)	184	83.26	16.82337	1.032292	1923.846	339.6114	
Above-recommendation (>18 $kgha^{-1}$)	27	12.22	18.94444	0.3489912	2179.525	355.8053	
Total	221	100	16.94796	1.366235	1940.73	361.0342	

***p<0.01; Standard error in parenthesis

Source: Computed from own survey data (2020)

Figure 3 illustrates the distribution of average yield across different seed rate user categories, namely below, within, and above the recommended seed rates. The data suggests a positive correlation between seed rates and *Korra tef* yields, indicating that higher seed rates are associated with higher yields across all seed use categories. The interpretation of this result suggests that providing a higher seed rate, up to and slightly exceeding the recommended doses, can potentially contribute to increased yields for *Korra tef* farmers. This observation may be attributed to the fact that all respondents in the study were beneficiaries of the AGP II program, which provided guidance on seed rates based on advice from local agricultural development experts. Please refer to Figure 3 for a visual representation of the distribution of average yield at varying seed rates.

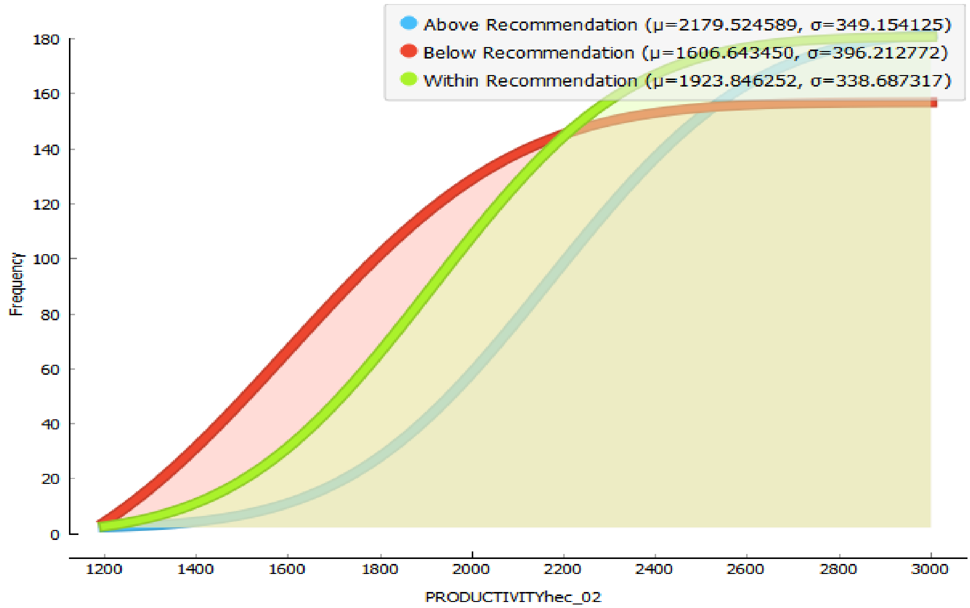

Figure 3.The distribution of average yield across varying seed rates

Source: Computed from own survey data (2020) and extracted by Orange Data Mining Software

3.2. Econometric results

The comparison drawn from the one-way ANOVA results needs to account for the seed rate's effects on yield fully. To examine the impact of a dose or concentration (*Korra* seed rate in this study) on the response (*Korra tef* yield) based on the generalized linear regression model, we thus used an analytical model of the dose-response function. However, since the study's doses were administered under controlled (rather than randomly assigned) conditions, the GPS was used to balance the variables that were considered. Accordingly, as shown in Table 7, the estimate of the GPS reveals that, except for the respondents' farm experiences (p = 0.040), the difference between the respondents was statistically not significant for all the variables selected as relevant (with the p values of >1%). This guaranteed that there was a relative balance of variables among the respondents. The presence of a relative balance suggests that the characteristics of the respondents are homogenous, which would enable us to quantify the effects of seed rate on yield objectively. The possibility that the AGP II has targeted farmers with comparable characteristics could be linked to the absence of notable variances among various seed dosage users. Since the key informants reported that farm experience was not one of the requirements for being program beneficiaries in the crop yield component, the slight variations in the respondents' farm experiences could be attributed to the criteria established by the program during the recruitment of the beneficiaries. The respondents confirmed that when farmers were recruited to adopt the *Korra tef* variety, the program did not use farm experience as a criterion.

Table 7.2 Estimation of the Generalized Propensity Score

Variables	Coef.	Std.Err.	z	P>z
SEX	-0.0071204	.0566026	-0.13	0.900
HHSIZE	0.0057116	.0073237	0.78	0.435
MARSTATUSHH	-0.0113463	.0174163	-0.65	0.515
FARMEXPHH	-0.0044818	.0021871	-2.05	0.040
TOTFARMLAND	0.0044647	.0508481	0.09	0.930
TLU	-0.0000972	.0077392	-0.01	0.990
MAINPARTCCOOP	-0.0000669	.0056192	-0.01	0.991
RADIOOWN	-0.0306982	.034691	-0.88	0.376
CREDUSE	-0.0399188	.0325014	-1.23	0.219
FTCDIST	-0.014042	.0154509	-0.91	0.363
MRKTDIST	-0.0024691	.0074901	-0.33	0.742
INONFARMACT	9.73e-08	2.27e-06	0.04	0.966
REMIT	-1.80e-06	4.58e-06	-0.39	0.694
_cons	1.010578	.2493589	4.05	0.000
Log-likelihood	21.09022662			
Number of obs	221			

Source: Computed from own survey data (2020)

The GPS was determined before the dose-response function was examined. Provided the sample respondents applied different seed rates, different predictive margins were used to examine the degree of change in *tef* yield. In light of this, the dose-response model was used to investigate the impacts of seed rate on yield. Five seeding rates (12, 14, 16, 18 and 20kgha^{-1}) were arranged. The model's analysis demonstrated that minimizing the seed rate typically lessened grain yield and that the more the respondents used seed rates close to the recommended doses, the greater their yield. The lowest seed rate of $12kgha^{-1}$ is correlated with the lowest average *tef* yield ($1222.24kgha^{-1}$).

On the other hand, by sowing the *tef* plants at the greatest seed rate, the highest grain yield ($1980.13kgha^{-1}$) was obtained ($20kgha^{-1}$). A direct correlation between the seed rate used and the amounts of yield obtained was observed between the two extreme margins of the seed rates (*i.e.* when $12kgha^{-1}$ and $20kgha^{-1}$ were applied), in which they both increase together and decrease together (see Table 8). Thus, by 9.57%, 19.14%, 28.71%, and 38.27%, respectively, the grain yield obtained from plants grown at the seed rate of $20kgha^{-1}$ exceeded the *tef* yields obtained from plants grown at the seed rates of 18, 16, 14, and 12. Thus, the *tef* grain yield obtained from plants grown at the seed rate of $20kgha^{-1}$ exceeded the *tef* yields obtained from plants grown at 18, 16, 14, and $12kgha^{-1}$ by 9.57%, 19.14%, 28.71%, and 38.27%, respectively.

According to this finding, it would be possible to increase output if farm households in the study area could use the *Korra tef* variety as recommended. The results are consistent with (Abraham et al. 2018), who found that in Ethiopia's *Ada*-District, East *Shewa*, a higher *tef* yield was obtained at the seed rate of $20kgha^{-1}$ than at 15, 10, 5, and $2.5kgha^{-1}$ seed rates. Similarly, (Sewnet, 2005) stated that in the *Fogera* area of northwestern Ethiopia, higher rice grain production was obtained at the seed rate of $120kgha^{-1}$ than at 60, 80, and $100kgha^{-1}$ seed rates. In contrast to the current findings, (Amare and Adane, 2015)'s study in Ethiopia's Eastern *Amhara* Region found that the maximum grain yields, $2527kgha^{-1}$ and $3067kgha^{-1}$, were obtained with the lowest seed rate, $5kgha^{-1}$, on black soil in the years 2012 and 2013, respectively. A study conducted at *Konso* and *Arbaminc*h in Southern Ethiopia by (Arega and Yemgnushal, 2018) also found that *tef* which was sown with a seed rate of $5kgha^{-1}$ significantly increased grain yield by 12.3%, 29%, 29.5%, and 31.7% when compared to *tef* that was sown at a rate of 10, 15, 20, and $25kgha^{-1}$, respectively. The same study by (Bekalu and Arega, 2016) found that *tef* that was sown at rates of 5 and $10kgha^{-1}$ enhanced grain production by 45.15% compared to that of *tef* that was sown at rates of 15, 20, and $25kgha^{-1}$. The fact that the grain yield per unit area varies obviously on the performance of individual plants, panicle density, as well as the total number of plants grown in the area could be the cause of these discrepancies (Angassa, 2007; Delessa, 2017; Baloch et al. 2002; Yirgalem et al. 2021; Abraham et al. 2018). Therefore, additional studies on various soil types, *tef* varieties, seasons, and locations are needed to make a firm proposal.

Table 8. Marginal effects of different seed rates on *tef* yield

Seed rate (kg)	Delta-method		t	*p* > |t|	[95% Conf. Interval]	
	Margin	Std. Err.				
12	12.22239	0.0655019	186.60	0.000	12.09401	12.35077
14	14.11711	0.0409203	344.99	0.000	14.03691	14.19732
16	16.01184	0.0195883	817.42	0.000	15.97345	16.05023
18	17.90657	0.0204495	875.65	0.000	17.86649	17.94665
20	19.8013	0.0421653	469.61	0.000	19.71865	19.88394

Source: Computed from own survey data (2020)

To sum up, the Dose-Response relationship characterizes the relationship between the seed rate (dose) applied at the plot level and the resulting yield (response). Figure 4 visually represents this relationship, with the dose displayed on the horizontal axis and the response on the vertical axis. By examining the slope of the dose-response curve, we can gain insights into the extent to which the desired response (yield) changes as the dose (seed rate) is altered. A steeply rising and protracted curve indicates that even slight changes in the dose can lead to substantial changes in the effect (yield) of the treatment (Calabrese, 2014). This suggests that within a broad range of seed rates, small adjustments can have a significant impact on *Korra tef* yield.

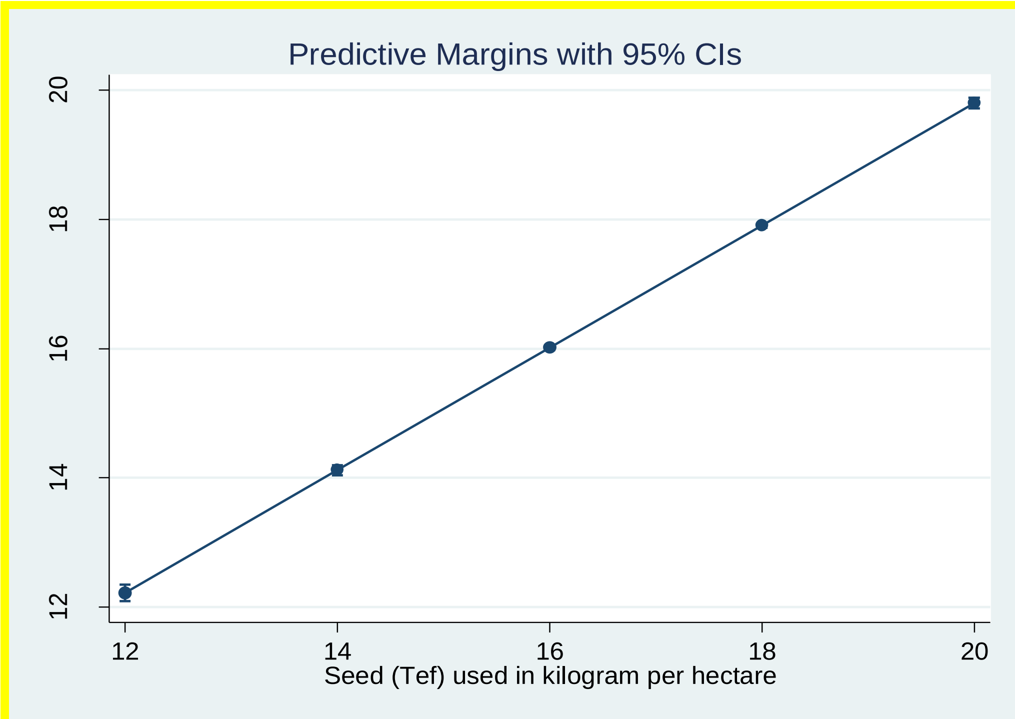

Figure 4. Seed rate-yield response curve
Source: Computed from own survey data (2020)

4. Conclusion and Recommendations

This study was conducted to examine the yield effects of plot-level *Korra tef* seed in Central Ethiopia (*Wara-Jarso woreda*) at the level of farm households that adopted one of the high-yielding *tef* varieties, *Korra*, during the 2020 cropping season. A one-way ANOVA conducted among different seed rate user categories as users below, above, and with recommendations showed that *Korra tef* yield was significantly (P=0.0003) affected by the seeding rate. Thus, substantial production differences were seen among the farmers that used seed rates below, within, and above the recommendations. The Dose-Response Model also showed that the treatments conducted at five levels of seed rates (12, 14, 16, 18, and 20 kgha^{-1}) produced the highest *tef* yield at the highest seed rate (20 kgha^{-1}), and the lowest *tef* yield at the lowest seed rate (12 kgha^{-1}). The grain yields obtained from plants produced at the seed rate of 20kgha^{-1} were higher by 9.57%, 19.14%, 28.71%, and 38.27%, respectively than the *tef* yields obtained from plants grown at the seed rates of 18, 16, 14, and 12kgha^{-1}. Thus, the *Korra tef* seed rate is a significant factor when estimating the crop's output.

Even though drawing any firm conclusions from a study of one season and one location is difficult, from the findings of this study, we commend using the *Korra tef* seed rate per the recommendation with a slight variation on the seed rate set as optimum for the study area (*i.e.* 15-18kgha^{-1}). With all other factors staying constant, the *Korra tef* variety in the study area can obtain a reasonably optimal yield by applying a seeding rate of roughly 20kgha^{-1}. Nevertheless, the yield effects of *Korra tef* seed rates for various soil types, tillage frequency, socio-economic settings, weather conditions, spatial arrangements, and other agricultural inputs (like fertilizers) should be investigated. This will have implications for future research that will help to contribute to the yield effects of plot-level seed rate and enrich the existing discussions and knowledge on the same. Furthermore, the current study needs to be repeated over the years with similar settings at multiple sites to confirm the results and develop solid and more conclusive recommendations that can be used by the farmers that grow *Korra tef*.

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Notes

Woreda: Woreda refers to the second smallest administrative level above the kebele and below the zone in Ethiopia, except the capital, Addis Ababa.

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FTCs (Farmers' Training Centers): FTCs are structures established in rural Ethiopia to support smallholder farmers. They were established throughout the country to train farmers on using technological packages and to facilitate agricultural extension services.

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