Received: 25 September 2018 | Revised: 25 September 2019 | Accepted: 14 October 2019

DOI: 10.1002/fes3.190

ORIGINAL RESEARCH

Food and Energy Security | WILEY

On-farm seed priming and fertilizer micro-dosing: Agronomic and economic responses of maize in semi-arid Ethiopia

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Funding information
Norwegian Ministry of Foreign Affairs

Abstract

On-farm seed priming has been reported to improve emergence, crop establishment, and yield besides improving economic benefits in dryland agriculture. These benefits can further be improved by fertilizer micro-dosing. The purpose of this study was to investigate the effect of on-farm seed priming and fertilizer micro-dosing on the agronomic and economic returns of maize (*Zea mays* L. var. Melkassa-2) in semi-arid agro-ecological conditions in Ethiopia. The experiments consisted of four treatments: no priming and no fertilizer; no priming and fertilizer; priming and no fertilizer; and priming and fertilizer. The experiments were conducted in three locations viz., Melkassa, Ziway, and Hawassa in the central Rift Valley. Analysis of variance for each location was performed separately at $p < .05$. Results of each location were similar over the experimentation years, and hence, there was no need for carrying out combined analysis. Regardless of fertilization, primed plants showed faster emergence; better uniform crop stands; more vigorous plants; earlier flowering; earlier harvest; and higher grain and stover yield than no primed plants. Germination was 2–3 days earlier, and flowering and maturation of primed plants were 10 to 13 days earlier than no primed plants. Average grain yield increased by 11, 8, and 6% in Melkassa, Ziway, and Hawassa, respectively, by priming over no priming. Fertilizer micro-dosing combined with priming further improved most of the agronomic characters. Fertilizer micro-dosing combined with priming increased the average grain yield by 75, 69, and 33% in Melkassa, Ziway, and Hawassa, respectively. The economic returns also increased in the same pattern as the agronomic responses for priming, micro-dosing or their combination. To realize the potential of seed priming of increasing agronomic performances, future research and development efforts should focus on understanding the possible underling physiological and biochemical basis of this poorly understood process with the different priming techniques.

KEYWORDS
agro-economic return, dryland agriculture, fertilizer micro-dosing, rainfall variability, seed priming

1 | INTRODUCTION

Maize (*Zea mays* L.) is a cereal crop that is grown widely throughout the world in a range of agro-ecological environments and is important both to subsistence and commercial farmers (FAO, 2004). In Ethiopia, maize is cultivated in all major agro-ecological zones, between elevations of 500 and 2,600 meters above sea level (Mulatu, Bogale, Tolessa, Desalegne, & Afeta, 1992). It plays a central role in food security, especially in the rural areas of Ethiopia. Per capita consumption of maize in rural areas is estimated at about 45 kg/year. More than 80% is consumed at the household level, with commercial marketing largely limited to large-scale producers. Although there are large-scale commercial farms engaging in maize production, smallholders and subsistence farmers represent 95% of its production (FAO, 2014). Moreover, among the cereals produced by farmers in Ethiopia, maize has the largest smallholder coverage with 8 million farmers compared to 5.8 million for *teff* (*Eragrostis tef* (Zucc.) Trotter) and 4.2 million for wheat. It is a staple and critical crop to smallholder livelihoods, especially to semi-arid farming communities where it is cultivated by over 95% of smallholders. Maize is the crop that produces calories at the lowest cost, providing 1.5 times and twice the calories per dollar compared to wheat and *teff,* respectively (CSA, 2013). Therefore, increasing the productivity of maize could promote Ethiopia's food production and reduce the national food deficit.

The semi-arid Africa is dominated by low yield and rain-fed farming system. The farming system is characterized by slow seed emergence, low vigor of seedlings, patchy plant stands, and frequent crop failure or yield reduction (Camara, Camara, Berthe, & Oswald, 2013; Harris et al., 2001; Sime & Aune, 2019; Sori & Tomer, 2011). These are common challenges in maize production in the semi-arid Rift Valley region of Ethiopia (Kassie et al., 2014; Sime & Aune, 2019). The region's maize production is highly variable due to occurrence of frequent dry spells, soil moisture stress, poor soil fertility, and lack of access to appropriate maize varieties. Consequently, the agronomic and economic benefits from maize are apparently low and are largely responsible for the low food security in the region (Beshir & Wegary, 2014; Biazin & Stroosnijder, 2012; Kassie et al., 2014). Improvement in water use efficiency for enhanced drought tolerance and improved crop yield can be achieved by different agronomic practices like on-farm seed priming (Harris, Joshi, Khan, Gothkar, & Sodhi, 1999; Harris et al., 2001). In soil moisture stressed conditions, it is possible that primed seedlings experience less stress due to faster germination and growth (Murungu et al., 2004). Thus, seed priming can be used as a strategy to mitigate the impacts of climatic variability and soil moisture stress on maize production.

There are several priming methods, which have been employed so far. The most commonly used methods are osmo-priming, soaking in a solution of osmoticum (Mahboob et al., 2015; Rouhi et al., 2011), halo-priming, soaking in salt solution (Nawaz, Amjad, Pervez, & Afzal, 2011; Tian et al., 2014), solid matrix priming, priming using solid carriers (Khan, 1992; Olszewski, Goldsmith, Guthrie, & Young, 2012), and hydro-priming, soaking in water (Afzal et al., 2002; Ahammad, Rahman, & Ali, 2014; Harris et al., 1999). This study used hydro-priming, which is the most cost effective and practical method that needs only water to prime seeds. Hydro-priming is a low cost, low risk, and simple practice that can be used by farmers to improve their livelihood. It involves soaking seed in water (usually overnight), surface-drying, and then sowing the same day. Yet, soaked seeds can be managed as nonprimed seeds if they are surface-dried and kept dry, and can be kept for several days and used for sowing. Moreover, farmers can prime their own seed once they know the "safe limits" that helps to avoid seed or seedling damage (Harris et al., 2001; Murungu et al., 2004). Moreover, the consequence of drying seeds after priming is opportunities for farmers to "add value" to their seeds, which delivers nutrient supplements and increase resistance to pests and diseases (Harris, 2006).

The aim of seed priming is, therefore, to rapidly hydrate seed in order to shorten the time to emerge. It advances germination by inducing a wide range of biochemical changes in seed. It is, thus, associated with faster seed germination, higher seedling vigor, stand uniformity, earlier flowering and maturation, higher yield, lower risk, and allows farmers a much wider choice of farm management options (Harris, 2006; Harris et al., 1999, 2001; Rashid, Harris, Hollington, & Khattak, 2002). Seed prioming has been shown to improve germination and establishment, promote earlier flowering, and greater yield in the semi-arid tropics (Finch-Savage, Dent, & Clark, 2004; Harris et al., 1999, 2001; Osman, Abdalla, Mekki, Elhag, & Aune, 2010). In particular, the benefits later in the growth of maize were much greater than might be expected from emergence 1–3 days earlier (Murungu et al., 2004). Although the level varies, priming has been used to increase productivity of maize in Zimbabwe, India, Pakistan, and Bangladesh (Harris et al., 1999, 2001; Murungu et al., 2004).

In association with seed priming, the other technology that can increase the productivity of maize in the semi-tropics is fertilizer micro-dosing (Abdalla et al., 2015; Camara et al., 2013; Sime & Aune, 2016). There are few reports on the combined effect of seed priming and fertilizer micro-dosing on crop production. The key results of these studies, that is, increased yield in sorghum and pearl millet in western Sudan (Aune & Ousman, 2011), maize in semi-arid Ethiopia (Sime & Aune, 2016), and sorghum and millet in the Sahel (Aune & Bationo, 2008). These studies were conducted under conventional tillage (Aune & Bationo, 2008; Aune & Ousman, 2011) and minimum tillage (Sime & Aune, 2016). Author's previous work (Sime & Aune, 2016), nevertheless, did not evaluate the separate effect of seed priming and fertilizer micro-dosing in maize, despite that the study was conducted under minimum tillage system. Further, Sime and Aune (2014) evaluated only the separate effect of fertilizer micro-dosing in maize, under conventional tillage system. Hence, the present study evaluates, as a new aspect, both separate and combined effects of seed priming and fertilizer micro-dosing on the agronomic and economic responses in maize, under the conventional tillage system.

We hypothesized that on-farm seed priming, fertilizer micro-dosing or their combination increases the agro-economic benefits in maize production. Each of the technologies can individually increase maize productivity. However, combining themcan further improve the agronomic performance and economic returns, thus, providing a potentially viable option for resource-poor farmers. The objective of this paper is, therefore, to evaluate the individual and combined effects of on-farm priming, fertilizer micro-dosing on maize agronomic performances and the economic returns, in the semi-arid central Rift Valley of Ethiopia.

2 | POTENTIAL OF SEED PRIMING, FERTILIZER MICRO-DOSING, AND THEIR COMBINATION IN AFRICAN AGRICULTURE

Efficient soil fertility management that aims at maximizing the agronomic efficiency of applied nutrients is vital for intensifying agriculture in Africa (Vanlauwe et al., 2011). Importantly, the use of proper fertilizer management and the adaptation of input application rates following soil fertility gradients are important (Vanlauwe et al., 2011). Addressing soil fertility decline is key to overcoming hunger in Africa (Sanchez, 2002). Nitrogen and phosphorus are often the most limiting nutrients for crop production in the tropics (Osmond & Riha, 1996). As a result, to reverse the trend of declining per capita food production, more intensive land use with fertilizer application has become necessary. Such a method can attract the poorest farmers' interest in fertilizer application. Fertilizer micro-dosing is an efficient fertilizer application method that can significantly reduce fertilizer rates and risks, and increases yields, thus, can be an available option for fertilizer application in Africa. Seed priming alone or in combination with fertilizer micro-dosing could have similar potentials for intensifying agricultural productivity in Africa.

Micro-dosing technology was developed to maximize the return on fertilizer investment (ICRISAT, 2009). Findings from a previous study indicated that micro-dosing technology increases yields and economic profitability (Camara et al., 2013). Such a method of fertilizer application entails a minimal economic risk and can contribute to higher yields and improve food security and farmers' income (Aune & Ousman, 2011; Camara et al., 2013; Sime & Aune, 2014). For traditional agriculture with low yields and no fertilizer input, micro-dosing could be used as an entry point toward a more productive and fertilizer input-based agriculture (Aune & Bationo, 2008; Camara et al., 2013). Moreover, to ensure agronomic sustainability and mitigate nutrient depletion, the use of organic manure or compost together with inorganic fertilizer in micro-dosing is promoted in the SSA (Camara et al., 2013).

Because the micro-dosing technology is low cost, low risk, and gives immediate agronomic and economic benefits, it may be attractive to farmers (Aune, Doumbia, & Berthe, 2007; Aune, Traoré, & Mamadou, 2012; Sime & Aune, 2014). Such immediate benefits are decisive in technology adoption. It is only when farmers can generate positive returns from the alternative practice that they adopt it. Micro-dosing of fertilizers has shown consistent results in on-station and large-scale on-farm studies. It appears to be a promising option for increasing crop productivity with a relatively limited input of resources (Camara et al., 2013). Moreover, smallholder farmers need robust technologies, which are not too demanding on skills, knowledge, and resources, but which improve productivity and/or yield stability. In addition to improving yields and minimizing input costs, fertilizer micro-dosing enhances fertilizer use efficiency, increases nutrient uptake, and saves fertilizer. For instance, it was reported to increase yield from 44% to 120% and farm income from 52% to 134% compared to the recommended dosage and farmers' practice in Niger (Tabo, Bationo, Diallo, Hassane, & Koala, 2006). In addition, micro-dosing can be applied after sowing without much penalty on yield (Camara et al., 2013; Hayashi, Abdoulaye, Gerard, & Bationo, 2008). The delayed fertilizer application can lessen the financial burden of farmers during the sowing period and give them another option to increase productivity and economic returns. Farmers can then have greater flexibility in managing their labor and cash resources.

Other technologies that are compatible with micro-dosing are seed priming (Aune & Ousman, 2011; Camara et al., 2013), ridging for water conservation (Aune & Ousman, 2011; Camara et al., 2013), organic fertilizers (Camara et al., 2013), and surface mulching (Sime & Aune, 2016). In marginally arid, semi-arid, and rain-fed areas in Africa, low-vigor seedlings and patchy plant stands resulting from failure of the crop to emerge quickly and uniformly are common challenges for farmers (Camara et al., 2013; Harris et al., 2001; Sime & Aune, 2016; Sori & Tomer, 2011). When farmers face patchy seedling establishment, they may re-sow, although this entails increased labor and financial costs. Seed priming advances germination by inducing a wide range of

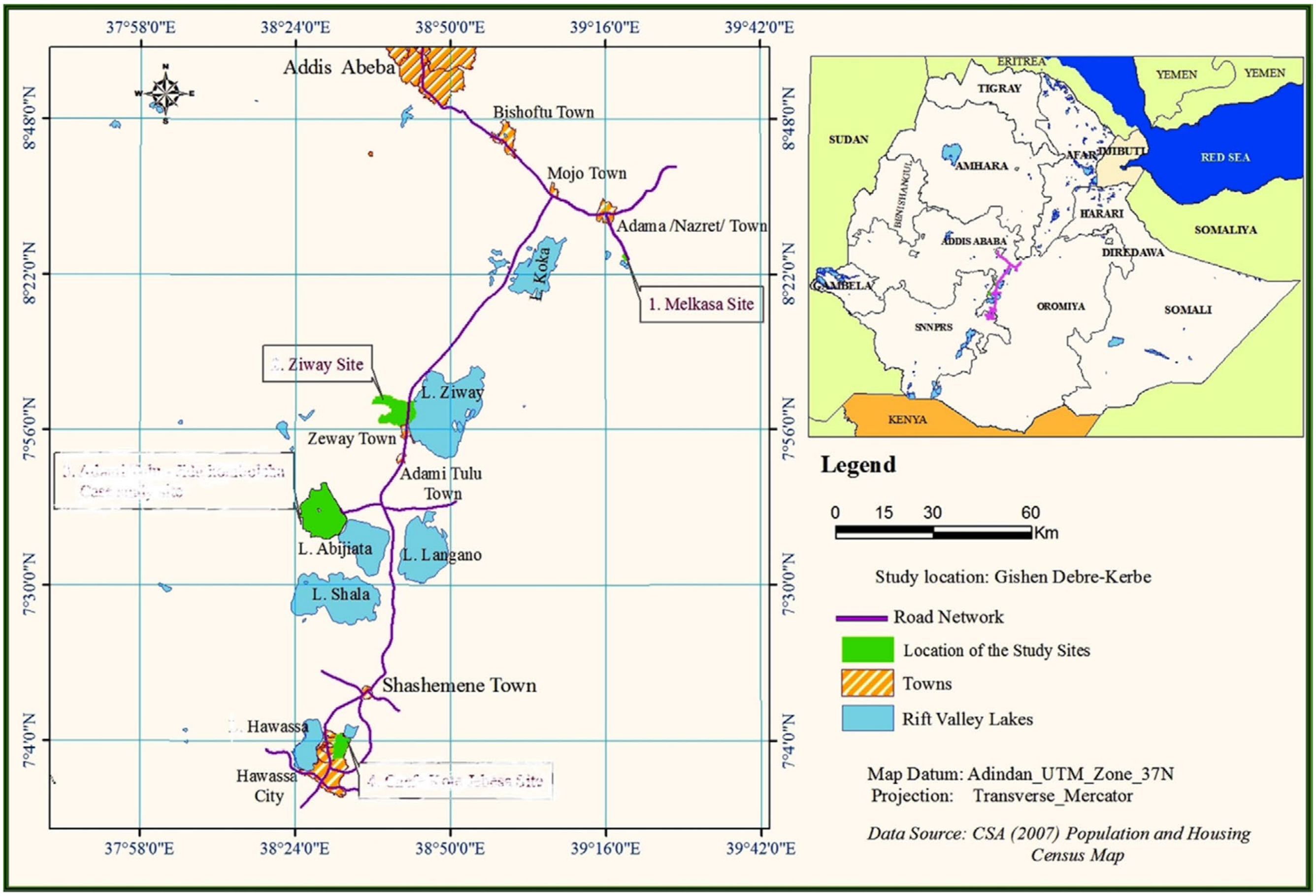

FIGURE 1 Location map of the study sites

biochemical changes in the seed. It is associated with faster seed germination, higher seedling vigor, improved stand uniformity, earlier flowering, maturation and harvesting, and higher yields (Ahammad et al., 2014; Aune et al., 2012). For instance, in the low-rainfall Africa, it increased yield in maize in Zimbabwe (Harris et al., 2001), in sorghum and millet in Sudan (Aune & Ousman, 2011), and in pearl millet in Mali (Aune et al., 2012). Additionally, the combination of seed priming with micro-dosing improves agronomic and economic returns in millet in low-rainfall regions in Mali (Aune et al., 2012), in sorghum and millet in west Africa, in sorghum and millet in Sudan (Aune & Ousman, 2011), in sorghum, groundnut, sesame, and cowpea in Sudan (Abdalla et al., 2015), and in maize in Ethiopia (Sime & Aune, 2016). Such a combination also decreases the risk of investing in fertilizer, keeping the value cost ratio above the minimum requirement (Aune et al., 2012; Sime & Aune, 2016). During low-rainfall, semi-arid, and rain-fed Africa, seed priming is, therefore, an important option available to farmers. Although seed priming and fertilizer micro-dosing are important alternatives for farmers in low-rainfall, semi-arid, and rain-fed Africa, only few attempts have been made so far to promote their adoption. Empirical reports on adoption rate by farmers of seed priming and micro-dosing or their combination is lacking and requires further investigation in Africa.

3 | MATERIALS AND METHODS

3.1 | Description of experimental sites

The study was carried out at three sites in the central Rift Valley, namely Ziway, Melkassa, and Hawassa (Figure 1). Ziway and Melkassa are located in East Shoa Zone in Oromia Regional State while Hawassa lies in Sidama Zone in Southern Nations, Nationalities and People Regional State, in southern Ethiopia. Melkassa and Ziway are located in the semi-arid agro-ecological zones. Hawassa is in the moist mid-highlands.

3.2 | Melkassa

Melkassa is located at 8°4′N latitude, 39°31′E longitude and lies at an altitude 1,550 m above sea level (m.a.s.l.). It is located at 115 km southeastern of Addis Ababa. Melkassa receives a mono-modal type of rainfall from June to October, which is the main cropping season for early maturing cereals and pulses (Table 1). The average maximum and minimum air temperature during the experimental period was 29°C and 14°C, respectively (Sime & Aune, 2014).

3.3 | Ziway

Ziway is located at 7°9′N latitude, 38°43′E longitude, an altitude of 1642 m.a.s.l and 122 km south of Addis Ababa. Ziway receives a bimodal rainfall from April to May and from June to October. June to October is the main cropping season for early maturing cereals and pulses (Table 1). Risk-taking farmers also plant mid-maturing maize varieties in April, which are often affected by the cessation of rain in late May. The average maximum and minimum air temperature during the experimental period was 28°C and 13°C, respectively (Sime & Aune, 2014).

3.4 | Hawassa

Hawassa is located at $7^0$4'N latitude, $38^0$31'E longitude, and lies at an altitude of 1675 m.a.s.l. It is located at 275 km south of Addis Ababa. It receives a bimodal rainfall with peak rainfall months in April and July, with the former (March to June) being the main cropping season for planting late and mid-maturing maize varieties (Table 1). The latter (June to October) is used for growing early maturing crops such as maize and pulses. The average maximum and minimum air temperature during the experimental period was 26.5°C and 14.0°C, respectively (Sime & Aune, 2014).

All the study sites are characterized by a mixed farming system, where both livestock and crop production are important agricultural practices and the mainstay of farmers' livelihoods. Despite providing dung for domestic fuel, cattle are important in the agricultural production system as they provide draught and threshing power as well as manure to improve soil fertility. Crop residues are used as livestock feed, domestic fuel, and construction material. Mono-cropping of cereals is commonly practiced, which is mainly composed of maize at Ziway and Hawassa, and *Teff* and maize at Melkassa.

TABLE 1 Average total annual and study period rainfall (mm)

	Annual (January to December)		Amount of rainfall during study period (June to October)		
Site	2012	2013	2012	2013	Annual rainfall (%)
Ziway	598	856	442	732	81
Melkassa	923	924	685	822	82
Hawassa	948	1,125	876	994	90

Source: Adami Tullu (Ziway) and Melkassa Meteorological Stations.

Moisture deficit areas occupy more than 60% of the land mass in Ethiopia (Mersha, 2000). Agriculture in the semi-arid central Rift Valley is primarily rain-fed and low yielding. It is affected by physical constraints like low soil fertility, high soil moisture stress, frequent intra-seasonal dry spells, and terminal drought (Belay, Bekele, & Ewunetu, 2013; Biazin & Sterk, 2013; Getachew & Tesfaye, 2015). Climate trends in the region, especially in terms of rainfall and its variability, pose major risks to the rain-fed agriculture. Therefore, the region needs specific adaptation strategies to cope with the risks, sustain farming, and improve food security (Kassie et al., 2014).

3.5 | Soil physical and chemical properties

The soil texture at Ziway is clay loam (40% sand, 32% silt, and 28% clay), with moderately alkaline pH at 8.40, 3.21% organic carbon (OC), 0.25% total nitrogen (TN), and 18.20 mg/kg available P. The soil at Melkassa is loam soil (37% sand, 40% silt, and 23% clay), with a slightly alkaline pH at 7.42, 1.7% OC, 0.14% TN, and 19.20 mg/kg available P. The soils at Ziway have lower available P and bulk density than the soils at Melkassa. There are slightly better conditions in the chemical properties, including electrical conductivity, OC, TN, exchangeable cations including potassium, sodium, calcium, and magnesium, and cation exchange capacity in Ziway soils than in Melkassa soils. Total porosity is similar in both sites (Sime & Aune, 2014).

The soil at Hawassa is a well-drained loam (46% sand, 28% silt, and 26% clay), with a slightly acidic pH at 7.1, 2.3% OC, 0.19% TN, and 46.40 mg/kg available P. Compared to the other two sites, Hawassa is a high potential area for crop production with better soil quality, rainfall, length of growing season, and other agro-ecological conditions. Because of relatively smaller landholding per households, farmers' soil management practices are better at Hawassa. Farmers use both organic and inorganic fertilizers. Among others, these might be the reasons for the remarkably high available P at Hawassa (Sime & Aune, 2014).

3.6 | Treatments, experimental designs, measurements, and analyses

The treatments were as follows:

(i) No priming seeds and no fertilizer (P_0M_0),
(ii) No priming and fertilizer (P_0M_f),
(iii) Priming and no fertilizer (PM_0), and
(iv) Priming and fertilizer (PM_f).

Where 0 denotes absence of priming or fertilizer application, P denotes priming, M denotes micro-dosing, and *f* denotes fertilizer application.

The fertilizer rate was 1 g per hill of diammonium phoshate (21%N and 46%P) applied at sowing and 1 g per hill of urea (46%N) applied at maize knee height. The control did not receive fertilizers. The DAP fertilizer was applied at planting. Any difference in the effects of the two types of fertilizer was not considered in the present study. This effect has been already reported in the author's previous publication (Sime & Aune, 2016). Agronomic and economic responses increased when urea was added, and responses were lower when only DAP fertilizer was used. Since emergence was better in primed plants than no primed plants, different total amounts of fertilizer were applied per ha. This was taken into account in the calculations of fertilizer use efficiency and economic returns. The treatments were arranged in a randomized complete block design with four replications. Plot size was 3 by 4.5 m, which corresponds to 6 rows of maize, spaced at 0.75 m between rows, and 0.25 m within rows. The plant population was about 53,333 per ha. Blocks were separated by 1.5 m apart. Different plots were used for the same treatments each year. One seed was sown per hill at 5 to 7 cm depth. Seedbeds were prepared by oxen with four strips using a traditional plow. Plots were kept weed-free by hand—weeding and hoeing. Weeding was carried out on the third and fifth week after sowing. The experimental crop was maize variety (*Zea mays* L. var. Melkassa-2), which has been recommended for semi-arid areas in the central Rift Valley that matures in about 120–130 days after sowing. It is among early maturing maize varieties released for dryland agriculture in Ethiopia.

Before each sowing date, seeds were primed by soaking in water overnight for 12 hr, then surface-dried for 1 hr by blotting with a dry cloth under shade. Maize seeds can be primed without damage for up to 24 hr (Harris et al., 1999), and farmers tended to prefer at 12 hr soaking time length overnight (Chivasa, Harris, Chiduza, Mashingaidze, & Nyamudeza, 2000; Harris et al., 1999).

Data were collected for number of days to emerge and to 50% germination, seedling uniformity and vigor, duration to 75% physiological maturity, stover yield, and grain yield. Seedling uniformity (rated 1 to 5 where: 1 = poor, 2 = low, 3 = moderate, 4 = uniform, 5 = very uniform). Seedling vigor (rated 1 to 5 where: 1 = poor, 2 = low, 3 = moderate, 4 = vigorous, 5 = very vigorous). The scale used for rating seedling uniform and vigor was based on the relative performances of treatments. These traits were measured after the seedling was established well, after the second weeding. Days to physiological maturity was taken when 75% of maize plants in a plot showed dried leaves and black scar on the kernels. Stover weight was taken after sun drying for nine to twelve days and when no change was observed between consecutive measurements. Threshing was done manually. Grain yield weight at harvest was measured and adjusted at 12.5% moisture level. To avoid border effects, data of all the parameters considered were taken from the four central rows; thus, the net plot size was 9 m^2.

The agronomic efficiency, risk, and profitability of using fertilizers were assessed by calculating fertilizer use efficiency (FUE), value cost ratio (VCR), and gross margin (GM).

3.6.1 | Agronomic fertilizer use efficiency

FUE: The agronomic FUE of each treatment was computed as the difference in yield (kg/ha) between each treatment and control divided by the amount of fertilizer applied (kg/ha).

$$\text{FUE} = \frac{Yt - Ct}{Ft}$$

where *FUE* is the agronomic fertilizer use efficiency of treatment t; Yt is the grain yield of treatment t; Ct the grain yield of the control treatment; and Ft is the rate of fertilizer used for treatment t.

Partial budgeting technique: It was used for the analysis of economic efficiency or profitability of each treatment. The GM was calculated to evaluate the economic response of each treatment. Cost of production for each treatment, including fertilizer, seeds, and labor (for priming, planting, fertilizer application, weeding, and harvesting), and revenue generated from the price index for grain yield (averaged over 2012 and 2013 cropping seasons) were collected from local markets where farmers buy inputs and sell their produce. Monetary values related to costs were converted from Ethiopian Birr to US$ at the exchange rate of one US$ equivalent to 18.46 Ethiopian Birr.

VCR: Fertilizer profitability is a function of fertilizer response (kilogram of additional output per kilogram of fertilizer used), fertilizer prices, and output prices. For each treatment, the VCR was calculated using yield increase of the treatment compared with the control, price per kg grain, kg fertilizer used and price per kg fertilizer used as follows:

$$\text{VCR} = \frac{\Delta Y * P}{Cf}$$

where ΔY denotes incremental yield gains resulting from fertilizer use between a treatment and control, P denotes price per kg of maize, and Cf denotes the cost of dose of fertilizer used per hectare.

This analysis was based on the average yields of each treatment; where a partial budget was used to calculate the net profit; VCR was calculated for each treatment. The VCR for each treatment measures the increase in revenue relative to the increased costs compared to the control treatment. It measures the economic (net return) return of fertilizer use.

TABLE 2 Effect of priming, micro-dosing, and combination on maize (var. Melkassa-2) yield components in 2012 cropping season and three sites

	Melkassa				Ziway				Hawassa			
Treatment	**PSG (%)**	**UNI (scale)**	**VIG (scale)**	**MAT (days)**	**PSG (%)**	**UNI (scale)**	**VIG (scale)**	**MAT (days)**	**PSG (%)**	**UNI (scale)**	**VIG (scale)**	**MAT (days)**
P_0M_0	89.25b	2.25b	2.25c	130a	85.5b	2.5c	2.25c	128a	90.25b	2.00c	2.25c	132a
P_0M_f	89b	3.00b	3.25b	123b	89.5b	3.5b	3.5b	124b	90.25b	3.00b	3.25b	125b
PM_0	93.75a	3.75a	3.00b	117c	93.75a	3.75ab	3b	117c	94.75a	3.50b	3.00b	122c
PM_f	93.75a	4.25a	4.00a	113d	93.75a	4.5a	5a	112d	94.75a	4.50a	4.25a	115d
R2	0.93	0.80	0.81	0.98	0.95	0.69	0.90	0.98	0.96	0.86	0.78	0.99
CV (%)	0.79	13.1	11.3	0.69	0.59	15.69	11.11	0.84	0.54	12.56	13.58	0.49
$LSD_{0.05}$	1.11	0.67	0.54	1.29	0.82	0.86	0.59	1.56	0.77	0.63	0.67	0.94

Note: Means in the same column with same letter are not significantly different at p value < .05.

Abbreviations: PSG, Percent seed germination; UNI, Seedling uniformity (rated 1 to 5 where: 1, poor, 2, low, 3, moderate, 4, uniform, 5, very uniform); VIG, Seedling vigor (rated 1 to 5 where: 1, poor, 2, low, 3, moderate, 4, vigorous, 5, very vigorous); MAT, Physiological maturity; P_0M_0, No priming and no fertilizer micro-dosing; P_0M_f, No priming and fertilizer micro-dosing; PM_0, Priming and no fertilizer micro-dosing; and PM_f, Priming and fertilizer micro-dosing; CV (%), Coefficient of Variation and LSD, Least Significant Difference.

TABLE 3 Effect of priming and fertilizer micro-dosing on percent germination, seedling uniformity and vigor, and days to maturity of maize (var. Melkassa-2) grown at three locations during the 2013 cropping season

	Melkassa				Ziway				Hawassa			
Treatment	**PSG (%)**	**UNI (scale)**	**VIG (scale)**	**MAT (days)**	**PSG (%)**	**UNI (scale)**	**VIG (scale)**	**MAT (days)**	**PSG (%)**	**UNI (scale)**	**VIG (scale)**	**MAT (days)**
P_0M_0	88.5b	2.00c	2.25c	128a	89.5b	2.5c	2.75c	127a	91.5b	2.00b	2.00c	132a
P_0M_f	88.5b	3.25b	3.25b	123b	89.25b	3.75ab	3.75b	124b	91.25b	3.50a	3.25b	124b
PM_0	94.25a	3.25b	3.75ab	118c	94.5a	3.5b	3.25ab	117c	94.75a	3.25a	3.50ab	123c
PM_f	94a	4.25a	4.5a	113d	94.5a	4.5a	4.25a	113d	94.5a	4.25a	4.00a	115d
R^2	0.95	0.81	0.76	0.99	0.97	0.69	0.63	0.99	0.66	0.62	0.83	0.99
CV (%)	0.82	13.58	15.14	0.66	0.61	15.69	14.29	0.45	1.44	22.65	11.98	0.52
$LSD_{0.05}$	1.16	0.67	0.80	1.22	0.86	0.86	0.77	0.83	2.06	1.13	0.59	0.99

Note: Means in the same column with same letter are not significantly different at p value < .05.

Abbreviations: PSG, Percent seed germination; UNI, Seedling uniformity; VIG, Seedling vigor; MAT, Physiological maturity; P_0M_0, No priming and no fertilizer micro-dosing; P_0M_f, No priming and fertilizer micro-dosing; PM_0, Priming and no fertilizer micro-dosing; and PM_f, Priming and fertilizer micro-dosing; CV (%), Coefficient of Variation and LSD, Least Significant Difference.

TABLE 4 Effect of priming, micro-dosing, and combination on maize (var. Melkassa-2) grain yield (GY) and stover yield (SY) in 2012 and 2013 cropping seasons

	Melkassa (kg/ha)				Ziway (kg/ha)				Hawassa (kg/ha)			
	2012		2013		2012		2013		2012		2013	
Treatment	GY	SY	GY	SY	GY	SY	GY	SY	GY	SY	GY	SY
P_0M_0	3559d	5889d	3710d	6583d	3867d	6639d	4068d	6889d	6313d	7194d	6640d	7139d
P_0M_f	5162b	7444b	6061b	8278b	6137b	8445b	6259b	8778b	7171b	9083c	7527c	8917b
PM_0	3799c	6612c	4291c	7083c	4233c	7194c	4338c	7556c	6812c	7750b	6910b	7917c
PM_f	6107a	8667a	6633a	9083a	6667a	9111a	6778a	9361a	8472a	9500a	8726a	9945a
R^2	0.98	0.88	0.99	0.95	0.99	0.94	0.99	0.97	0.96	0.97	0.96	0.99
CV (%)	3.07	6.26	1.35	3.18	1.63	3.51	2.09	2.32	2.94	2.14	2.10	1.74
$LSD_{0.05}$	220.3	490.1	106.2	380.4	131.4	423.9	173.2	291.3	328.6	276.3	239.4	227.6

Note: Means in the same column with same letter are not significantly different at *p* value < .05.
Abbreviations: GY, Grain yield; SY, Stover yield; P_0M_0, No priming and no fertilizer micro-dosing; P_0M_f, No priming and fertilizer micro-dosing; PM_0, Priming and no fertilizer micro-dosing; and PM_f, Priming and fertilizer micro-dosing; CV (%), Coefficient of Variation and LSD, Least Significant Difference.

TABLE 5 Priming and micro-dosing effects on fertilizer use efficiency and value cost ratio

	Hawassa		Ziway		Melkassa	
Treatment	FUE	VCR	FUE	VCR	FUE	VCR
P_0M_0	–	–	–	–	–	–
P_0M_f	12	4	24	8	20	6
PM_f	25	8	33	10	30	10
PM_0	–	–	–	–	–	–
P_0M_f	9	3	17	5	14	4
PM_f	22	7	25	8	24	8

Note: P_0M_f and PM_f are listed twice in the treatment column with different values because they are compared with different control groups (P_0M_0 and PM_0), under priming and no priming circumstances.
Abbreviations: FUE, Fertilizer use efficiency; VCR, Value cost ratio¸ P_0M_0, No priming and no fertilizer micro-dosing; P_0M_f, No priming and fertilizer micro-dosing; PM_0, Priming and no fertilization, and PM_f, Priming and fertilizer micro-dosing.

Gross Income (*GI*): It was calculated from grain local market price.
Total Variable Cost (*TVC*): It was calculated as the sum of labor and input costs.
GM: For each treatment, GM was calculated as the difference between GI and TVC, that is, GM = GI – TVC.

3.7 | Statistical analyses

Analyses of variance were carried out using a statistical analysis system (SAS) software version 9.4 (SAS, 2011). Wherever there were significant differences, mean separations were carried out using the Least Significant Difference (LSD). Significant differences between means of treatments were determined at the 5% significance level ($p < .05$). The statistical analysis of data for each location and season was carried separately. The statistical analysis compared the effects of treatment (comparison between treatments) separately on a yearly basis. All the treatments were compared with each other and the control to assess performances and all the available options for farmers. The results obtained from both seasons across sites were nearly similar, suggesting similar results for the combined analysis. That is why author did not perform a combined analysis of variance/pooled data analysis. Further, due to high intra-and interseasonal rainfall variability in the study areas, authors were also interested in evaluating the performances of the treatments under different amount of rainfall events.

4 | RESULTS

Tables 2, 3, and 4 depict the agronomic results of the 2012 and 2013 cropping seasons and Tables 5 and 6 the combined economic results over the two seasons and sites. The agronomic results considered in this study were days to emerge, percent seed germination, uniformity, days to maturity and yields, while the economic results were fertilizer use efficiency, value cost ratio, labor, gross income, and gross margin.

4.1 | Yield components and yields

Individually, both priming and fertilizer micro-dosing were able to significantly improve most of the agronomic characters across sites. Apart from that, generally the highest agronomic returns were obtained at all sites when both priming and micro-dosing were combined, particularly seedling uniformity, seedling vigor, days to maturity and stover and grain yields (Tables 2, 3, and 4).

TABLE 6 Priming, micro-dosing, and combination effects on labor requirement (day/ha), gross income, and gross margin (US$ /ha)

	Hawassa			Ziway			Melkassa		
Treatment	LR	GI	GM	LR	GI	GM	LR	GI	GM
P_0M_0	28b	1323d	1245d	28b	911d	808d	28b	840d	715d
PM_0	29b	1393c	1312c	29b	950c	844c	29b	890c	788c
P_0M_f	42a	1596b	1383b	43a	1397b	1139b	42a	1388b	1020b
PM_f	43a	1920a	1704a	44a	1496a	1288a	43a	1427a	1213a
LSD (<0.05)	1.5	34.9	35.3	1.6	21	20.5	1.8	23.5	23.4

Note: Means in the same column with same letter are not significantly different at *p* value < .05.
Abbreviations: LR, Labor; GI, Gross Income; GM, Gross Margin; P_0M_0, No priming and no fertilization; P_0M_f, No priming and fertilization; PM_0, Priming and no fertilization, and PM_f, Priming and fertilization and LSD, Least Significant Difference.

4.1.1 | Days to emergence, seedling growth, and days to maturity

Across sites and experimental seasons (Tables 2 and 3), primed plants emerged significantly earlier than no primed plants. Similarly, seedlings from primed plants had significantly higher percent seed germination, uniformity and vigor than the seedlings from no primed plants. Primed plants also matured significantly earlier than no primed plants. Primed but non fertilized plants tended to have the same pattern of emergence rate, seedling uniformity, and vigor, as no prime but received fertilizer. Across sites and cropping seasons (Tables 2 and 3), primed plants performed significantly ($p < .05$) superior to no primed plants.

Fertilizer application did not significantly affect days to emergence and percent seed germination in neither primed nor non primed seeds. However, it significantly increased seedling uniformity and vigor compared to no fertilized plants as well as to most no primed plants. No fertilizer, but primed plants tended to have similar seedling uniformity as that of non primed but fertilized plants. However, they mostly had significantly lower vigor. Fertilizer application to primed plants further improved uniformity, vigor and days to maturity (Tables 2 and 3), showing the synergy between seed priming and fertilizer micro-dosing.

4.1.2 | Grain and stover yield

Across sites and cropping seasons, priming significantly increased maize stover and grain yields over no priming. Likewise, fertilizer application significantly increased stover and grain yields over non primed and non fertilized treatment. Priming increased the average grain yield by 11, 8, and 6% in Melkassa, Ziway, and Hawassa, respectively, compared to no priming. However, the grain yields were further increased, respectively, by 75, 69, and 33%, when priming was combined with micro-dosing. Stover yields increased in an almost the same pattern. This means that the combination of priming and micro-dosing enormously increased both grain and stover yields (Table 4). The increase in grain yield at Hawassa was more than double compared to Melkassa and Ziway. Besides having relatively better soil fertility status, Hawassa receives higher amount of annual and seasonal rainfall (Table 1).

4.2 | Economic responses

Individually, both seed priming and fertilizer micro-dosing increased economic responses in maize (Table 5). Generally, like for agronomic performances, the highest returns were obtained at all sites when both priming and micro-dosing were combined: fertilizer use efficiency, value cost ratio, and gross margin were all improved across sites (Table 5):

4.2.1 | Fertilizer use efficiency and value cost ratio

Across sites, fertilizer micro-dosing increased both fertilizer use efficiency and value cost ratio under both priming and no priming. This increase was much higher in Ziway and Melkasa. The increase in fertilizer use efficiency and value cost ratio was much higher under priming than no priming. Combining priming and micro-dosing kept the value cost ratio above the minimum value of four (Table 5). The fertilizer use efficiency also followed a similar pattern.

4.2.2 | Labor requirement, gross income, and gross margin

Across sites (Table 6), the labor needed for priming was not significantly higher than no priming. However, it was significantly higher for fertilizer micro-dosing compared to no fertilizer application even when combined with priming.

There is no meaningful extra labor cost to be incurred for priming. Monetary returns to the use of priming were significantly increased over no priming. Monetary returns also increased by fertilizer application over no fertilizer. However, the monetary returns were further increased when priming and fertilizer micro-dosing were combined. This showed that the economic returns were increased in an almost same way as agronomic returns for priming, micro-dosing, or their combination.

5 | DISCUSSION

5.1 | Maize establishment, duration to maturity and yield

In response to the prevailing rainfall variability and shorter window period for sowing and the cropping season in the central Rift Valley, this study used an early maturing maize variety (var. Melkassa - 2). The Melkassa Agricultural Research Centre, Ethiopia, has released this variety. This maize variety matures far earlier than local and hybrid maize varieties, which are also grown by the farmers. Priming hastens the earliness of this variety further. Thus, priming induced faster seed germination and shorter days to flowering and harvesting. The other priming-related agronomic benefits include higher seedling vigor, improved stand uniformity, better drought tolerance, and higher stover and grain yields. These results are consistent with findings from previous studies (Harris, 2006; Harris et al., 1999, 2001; Harris, Rashid, Hollington, Jasi, & Riches, 2002; Rashid et al., 2002).

As priming shorten the duration of the maize crop, priming can increase farmers' choice of maize varieties to grow each season. Further, it can help farmers replant extra early maturing maize and haricot bean when a crop failure occurs early in the season, providing farmers with additional cropping opportunities. Thus, priming can be taken as a good insurance to the vulnerable farming system in the central Rift Valley. Belay, Recha, Woldeamanuel, and Morton (2017) reported that 90% of farmers in the central Rift Valley have already perceived climate variability, and 85% have attempted to adapt practices like crop diversification, planting date adjustment, soil and water conservation and management, and increasing the intensity of inputs. Thus, further shortening of the duration to maturity and harvest in maize by seed priming could be a viable, drought escaping strategy.

Fertilizer micro-dosing at planting improves the agronomic performance of maize by improving seedling uniformity and vigor, shortening days to maturity and harvest, and higher yields. Fertilizer application does not improve emergence and percent seed germination. However, the benefit of seed priming and micro-dosing is considerably superior when they are combined. The agronomic benefits resulting from priming is further improved by fertilizer application. This combination in turn further reduce the vulnerability of maize to the impact of rainfall variability and terminal drought in the central Rift Valley. These results are consistent with other results that seed priming and fertilizer micro-dosing improves agronomic and economic returns of millet in low-rainfall regions of Mali (Aune et al., 2012), of sorghum, sesame, groundnut, and cowpea in the semi-arid Sudan (Abdalla et al., 2015), and of maize in semi-arid Ethiopia (Sime & Aune, 2016). Since seed priming reduces the risk of crop failure, it could therefore improve the interest of farmers to use fertilizers in maize production, with the combination being a preferable option. The combination could, thus, provide a win–win scenario for farmers. Studies in the central Rift Valley of Ethiopia showed that seasonal rainfall is highly unpredictable and variable with high risks of crop failure and low productivity (Belay et al., 2013), which escalates farmers' risk-averse behavior, discouraging them from investing in expensive fertilizers (Kassie et al., 2014). Previous studies concluded that on-farm seed priming is a simple, low cost, low risk intervention that represents a good insurance for risk-averse, resource-poor farmers (Abdalla et al., 2015; Aune & Ousman, 2011; Camara et al., 2013; Hayashi et al., 2008; Osman et al., 2010).

On the other hand, the increase in average grain yield by 11, 8 and 6% in Melkassa, Ziway, and Hawassa, respectively, showed that the benefits of seed priming over no priming decrease with increasing rainfall. That is, priming is more effective in areas receiving the relatively low amount of rainfall. Melkassa and Ziway receive a lower amount of annual and seasonal rainfall than Hawassa. Likewise, the increase in both fertilizer use efficiency and value cost ratio in Ziway and Melkasa shows that fertilizer application is more effective in areas with relatively low soil fertility status. Melkassa and Ziway have poorer soil fertility condition than Hawassa, and hence the better response. This shows that coupling seed priming and fertilizer micro-dosing is more effective and productive in relatively low-rainfall and low soil fertility condition.

5.2 | Fertilizer profitability, gross margin, and agronomic fertilizer use efficiency

Priming does not increase labor over no priming, but increases gross margin significantly. Priming reduces weed density and increases pest tolerance. In agreement with a finding from a previous study (Harris, 2006), priming reduces the drudgery of weeding and pest management. Priming could offer these indirect economic benefits. Micro-dosing technique, on the other hand, requires higher labor for fertilizer application. However, it offers higher fertilizer use efficiency, value cost ratio, and gross margin. Following the variation in agro-ecological setting of the three study areas, the value cost ratio, and the fertilizer use efficiency range between 7 and 10, and

22 and 33, respectively. Fertilizer micro-dosing increases both value cost ratio and fertilizer use efficiency, increases maize productivity and reduces the financial investment in applying fertilizer, thereby minimizing the financial risk of farmers (Sime & Aune, 2014). This shows that micro-dosing can reduce farmers' cash outlay and risk, thereby making the use of fertilizer more attractive. In the Sahelian region, it was indicated that crop productivity can be increased with fertilizer micro-dosing at a low cost and very moderate risk to farmers (Aune & Bationo, 2008). The combination of priming with micro-dosing also decreases the risk of investing in fertilizer, keeping the value cost ratio above the minimum requirement, which is consistent with findings from earlier studies (Aune et al., 2012; Sime & Aune, 2016). Like for the agronomic returns, the combination increases the economic benefits further compared to the economic benefits from either priming or micro-dosing. Micro-dosing of fertilizers offers such a possibility to increase farm productivity, in combination with priming yielding additional agronomic and economic benefits (Sime & Aune, 2016), which substantiates the result from the present study.

Regarding yield improvement due to treatment effects, in authors' previous studies and the present study, the treatment that actually work better is the combined use of seed priming and fertilizer micro-dosing. Irrespective of tillage systems (conventional and conservation tillage systems), this treatment performs better in terms of agronomic performances and economic returns in maize. The performance of this treatment is consistent with both authors' previous studies and the present study. In the author's opinion, the results from this study, thus, add additional information to what is already known about these technologies. Particularly, the promising agronomic and economic responses from combining priming and micro-dosing added novelty of the present study. Furthermore, studies on the economic responses from combined seed priming and micro-dosing are scanty, particularly in SSA. Thus, the results from these studies suggest that these technologies to be a viable option in the SSA agricultural system. Particularly, farmers who operate in the dry lands, with variable rainfall and severe soil moisture stress and soil fertility, can be potential beneficiaries of priming or its combination with micro-dosing.

6 | CONCLUSION

On-farm seed priming and fertilizer micro-dosing are a cheap, low risk, productive, and profitable techniques in maize production. Days to emergence, percent seed germination, seedling uniformity and vigor, days to maturity, stover, and grain yields were all significantly improved by priming seed with water. All the yield components except percent seed germination were significantly improved by fertilizer micro-dosing. Combining seed priming and micro-dosing boosts the benefits that can be obtained from either seed priming or micro-dosing. The economic benefits, including fertilizer use efficiency, value cost ratio and gross margin are improved in the same order. Shorter duration to maturity and harvest reduces vulnerability of maize to terminal drought and yield reduction. This could encourage farmers to apply fertilizers. Farmers are reluctant to use the recommended fertilizer rate due to high price and variable rainfall condition. The positive merits of seed priming and micro-dosing can give farmers a new option to increase yield. Combining seed priming and fertilizer micro-dosing offers the best agronomic performances and economic returns in maize production. Contextually, these agricultural practices are new in the farming systems in Ethiopia. They have a huge potential of increasing agricultural productivity, particularly in the drylands. This positive effect of on-farm seed priming and fertilizer micro-dosing on maize agronomic performance and economic return is particularly important in further increasing the national attempt to increase the production of maize in Ethiopia. Finally, future research needs to test the combined benefits of seed priming and fertilizer micro-dosing with other crops and under different rainfall conditions. The author recommends dissemination of the technologies to a wide range of farmers to improve the agronomic and economic performances of maize. We are planning to work with, farmers, agricultural researchers, and policymakers on the dissemination of the technologies to improve the agronomic and economic performances of maize under different agro-ecological conditions.

ACKNOWLEDGMENTS

The Norwegian Ministry of Foreign Affairs funded this research through the institutional collaboration between Hawassa University, Ethiopia and Norwegian University of Life Sciences, NMBU, Norway. The agricultural extension workers, experts, and farmers are grateful for their unreserved assistance during the experimentation time. They provided useful insights and assistance to the researchers. The district agriculture and rural offices are also thanked for their generous hospitality and support.

CONFLICT OF INTERESTS

The author declares that there are no competing interests.

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How to cite this article: SimeG, AuneJB. On-farm seed priming and fertilizer micro-dosing: Agronomic and economic responses of maize in semi-arid Ethiopia. *Food Energy Secur*. 2019;00:e190. https://doi.org/10.1002/fes3.190