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Effect of planting time and fungicide application frequency on severity of late blight (*Phytophthora infestans*), yield and yield components of potato (*Solanum tuberosum* L.) at Kulumsa, Southeast Ethiopia

Getachew Kebede Tufa[1,2*], Fekadu Gebretensay Mengistu[2] and Gezahegn Berecha Yadessa[1]

[1]College of Agriculture and Veterinary Medicine, Jimma University, P. O. Box 307, Jimma, Ethiopia.
[2]Kulumsa Agricultural Research Center, Ethiopian Institute of Agricultural Research (EIAR), P. O. Box 489, Asella, Ethiopia.

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Phytophthora infestans is the major bottleneck in potato production in Ethiopia. Selection of appropriate planting time is highly location specific and the most important subject in rain-fed potato production. However, research recommendation on optimum planting time and fungicide application frequency for high lands area of Arsi (Kulumsa) is lacking. Thus, field experiment was carried out to evaluate the effect of planting time and fungicide application frequency on disease severity, yield and yield components of potato at Kulumsa during main cropping season of 2017. The treatments consisted of four planting time in the months of June and July and four fungicide application frequencies at the rate of 2.5 kg ha^{-1} of Ridomil Gold M.Z 68% W.P. Treatments were combined in 4 × 4 factorial arrangement and laid out in randomized complete block design with three replicates. Data on disease, tuber yield and yield components were analyzed using Statistical Analysis System Version 9.3. The interaction effect between treatments showed a highly significant (p<0.01) effect on disease incidence and area under disease progress curve and a significant (p<0.05) effect on percent severity index. Early planting in June produced significantly higher number of marketable and total tuber numbers per hill which were progressively reduced in subsequent plantings, whereas delay planting in July resulted in higher number of unmarketable tubers per hill. The interaction between early planting and different fungicide application frequencies gave the highest average tuber weight, marketable and total tuber yield per hectare. Therefore, the combination of early planting in June and twice fungicide application gave the optimum results in the study area.

Key words: Disease incidence, fungicide, integrated disease management, potato tuber, production season.

INTRODUCTION

Potato (*S. tuberosum* L.) is one of the major economically important crops worldwide. On a global scale, potato is the most important tuber crop, ranking first in volume produced among root and tuber crops followed by cassava, sweet potato, and yam (Central Statistical Agency, 2016). Potato is an excellent smallholder farmer crop in the highlands of Ethiopia, and serves as both a cash and food security crop (Tesfaye, 2010).

In Ethiopia potato is grown by approximately more than one million HHs on an area of ~ 0.3 million ha (Central Statistical Agency, 2016). But according to Central Statistical Agency (2015), potato occupied 67,367.87 ha of land for main cropping season. The national average productivity of potato is very low (11. 8 t. ha^{-1}), compared to the world's average yield of 19 t. ha^{-1} (Central Statistical Agency, 2014). The small area coverage during main cropping season and low yield are mainly attributed to the prevalence of various insect pest and diseases (mainly late blight), low input use, lack of information on adequate disease management and lack of information on selection of favorable environmental conditions for planting time (when to plant), the insufficient seed tuber quality and the unavailability of seed tubers of improved varieties that have prevented growers from achieving full yield potential (Adane et al., 2010).

Among the major factors affecting potato production, late blight (*Phytophthorainfestans* (Mont.) de Bary) is one of the most devastating diseases in Ethiopia mainly due to poor knowhow to properly control the disease (Guchi, 2015). It affects both potato foliage in the field and tuber in the storage which can destroy a crop, causing up to 100% crop loss (Tsedaley, 2014).

Nowadays, late blight disease is becoming a major limiting factor affecting potato production in highland areas of Ethiopia. Despite the prevalence and seriousness of late blight causing losses to the potato crop in Ethiopia, adequate studies have not been made on the management of the disease using integrated management options than using fungicides alone. Planting time is one of the potential factors which need to be addressed in relation to occurrence and severity of late blight disease in potato production. However, in Arsi highlands, there is no recommended planting time combined with optimum application frequency of fungicide to reduce severity of late blight. Due to lack of information on appropriate planting time and optimum application frequency of fungicide, farmers in the study area (Kulumsa) plant potato at any time of main rain season starting from early onset of rain fall with once, twice or without fungicide application frequency. Besides, use of integrated disease management is limited in the study area despite of its use in reducing cost of production as well as environmental risks. This study evaluated the interaction effect of planting time and fungicide application frequency on late blight severity, yield and yield components of potato in the study area to identify the optimum planting time and fungicide application frequency for potato production in the study area.

MATERIALS AND METHODS

Description of experimental site

The experiment was conducted at Kulumsa Agricultural Research Center (KARC) which is located at 8° 00' to 8° 02'N latitude and 39° 07' to 39° 10'E longitude at an elevation of 2210 m above sea level (m.a.s.l) in Tiyo District, Arsi Administrative Zone of the Oromia Regional State, 167 km Southeast of Addis Ababa. The research center is located on a very gently undulating topography with a gradient of 0 to 10% slope. It has a low relief difference with altitude ranging from 1980 to 2230 meters (Abayneh et al., 2003). The agro- climatic condition of the area is wet with 832 mm mean annual rain fall and has a uni- modal rainfall pattern with extended rainy season from March to September. However, the peak season is from July to August. The mean annual maximum and minimum temperatures are 23.2 and 10°C, respectively (KARC metrological station, unpublished data). The coldest month is December whereas March and May are the hottest months. KARC has three major soil types: EutricVertisol, VerticLuvisol and VerticCambisol (Abayneh et al., 2003).

Experimental material, design and treatment

The experiment was carried out using Gudenie potato cultivar which was released by Ethiopian Institute of Agriculture Research (EIAR), Holota Agricultural Research Center (HARC) (Gebremedhin et al., 2008). Gudenie cultivar gives an average yield of 29 tons ha^{-1} under researchers' management and 21 tons ha^{-1} under farmers' management. It was tolerant to late blight at the time of release before a decade, but now its tolerance has decreased with time mainly in the main ('meher') production season with rainfall. Even if there are high yielders and recently released late blight tolerant potato cultivars like Belete and Dagim for high land of Ethiopia, the farmers in Arsi high lands prefer Gudenie for its better test, attractive color and marketability.

The treatments consisted of four planting time (15th of June, 30th of June, 15th of July and 30th of July) in combination with four fungicide application frequencies of Ridomil Gold M.Z 68 % W.P (No spray/control, once, twice, and three times at ten days interval spray from disease on-set) which was arranged in a 4 x 4 factorial arrangements in a Randomized Complete Block Design (RCBD) with three replications.

Experimental procedures

Land preparation was done in late May, 2017 by using tractor mounted plow and human labor. Plantings were done on 15th and 30th of June and July. Medium sized (35- 55 mm in diameter) and well sprouted seed tubers were planted manually on a plot size of 3 m x 3 m with planting spacing of 0.75 m × 0.3 m inter and intra-row, respectively at 5 cm depth (Mohammad et al., 2013). They were done in prepared ridges during the main cropping season after the rain commenced; the soil was moist enough to support emergence. Spacing between plots and blocks/replications was 1 and 2 m, respectively. Fertilization: NPS as a source of phosphorus

*Corresponding E-mail: kebedeg5@gmail.com; fgebretensay@yahoo.com.

by considering the amount of phosphorus and nitrogen in DAP and Urea as a source of nitrogen were applied at a rate of 236 and 144 kg ha^{-1}, respectively, following previous recommendations by Sertsu et al. (2003). The NPS was applied once at planting, below the tubers, while the urea was applied in splits, half at planting and half at full emergence (30-45 days after planting), as a side dress. First spray of fungicide (Ridomil Gold M.Z 68% W.P) was just at the initial appearance of disease symptoms using knap-sack sprayer. The fungicide was applied at the rate of 2.5 kg ha^{-1} using 400 L of water (0.00625 g/ ml) based on Syngenta Group Company (2010) recommendation. All agronomic practices such as weeding and cultivation were kept uniform for all treatments in each plot (Gebremedhin et al*.,* 2008; Amin et al., 2013).

Data collection and analysis

Phenology and growth parameters

Data on days to emergence, days to flowering, days to physiological maturity, plant height (cm), and number of stems per plant were collected accordingly from the inner rows per treatment. Leaf area index was estimated by sampling six plants from each plot randomly. Individual leaf area of the potato plants was estimated from individual leaf length using the following formula developed by Firman and Allen (1989) and leaf area index was determined by dividing the total leaf area of a plant to the ground area covered by a plant.

$$\text{Log 10 (Leaf area in cm}^2\text{)} = 2.06 \times \text{log 10 (Leaf length in cm)} - 0.458$$

Disease parameters

Incidence and severity of late blight disease were considered. Natural inoculation was considered to be the source of the disease under evaluation. The first reading of disease incidence and severity started on the onset of late blight and assessed on the central two rows every week. Incidence of late blight was assessed by counting the number of plants on the middle two rows and expressed as percentage of total plants. Six plants were taken randomly from each replicate per plot, and then five leaves of each plant were used to determine the disease severity (Forbes et al*.,* 2014). Disease severity was evaluated as the percentage of foliage area that is infected and 1-9 disease scale described by Heinfnings (1987).

Disease Severity Index was calculated from disease severity on the basis of the percentage of leaf area affected by late blight and calculated for each disease assessment using the following formula.

$$\text{Disease severity index (\%)} = \frac{\textbf{Summation of numerical rating}}{\textbf{Number of plants Examined x Maximum disease score}} \mathbf{X\ 100}$$

The disease severity index of foliar blight was expressed in percent of the infected leaf area used for disease rating scale given depending on the final record of percent severity index as per the scale (Heinfnings, 1987).

Days to first disease appearance (DDA) were recorded by counting days from planting to the first appearance of late blight symptom in each plot.

Area under the disease progress curve (AUDPC) was calculated using disease readings which were taken on the basis of the percentage of leaf area affected by late blight using the midpoint formula (Campbell and Madden, 1990; Forbes et al*.,* 2014).

$$AUDPC = \sum_{i=1}^{n-1} \frac{(yi + yi + 1)}{2} (t_{\mathrm{i}+1} - t_i)$$

Where, "t"is the time of each reading, "y" is the percentage of affected foliage at each reading and n is the number of readings. The variable "t" can represent Julian days, days after planting or days after emergence.

Yield and yield components

Data for yield and yield components were collected and computed for each treatment and treatment combinations. The parameters included tuber size distribution, average tuber weight(g), marketable tuber number per hill, unmarketable tuber number per hill, total tuber number per hill, marketable tuber yield (t/ha), unmarketable tuber yield(t/ha) and total tuber yield (t/ha). The aforementioned parameters were computed from six randomly selected plants from the mid rows.

Tuber size distribution per plot: The harvested tubers were cleaned and sorted into size categories per plot using caliper. Tubers below diameter of 20 mm were considered as undersized, which is unmarketable and the rest of the tubers were small size (20-30 mm), medium size (30-40 mm) and large size(>40 mm).

Statistical analysis

Data were subjected to analysis of variance (ANOVA) using the General Linear Model of the SAS statistical package (SAS, 2009) version 9.3. All significant pairs of treatment means were compared using the Least Significant Difference Test (LSD) at 5% level of significance (Montgomery, 2005). Correlation analysis was performed to determine the association of disease parameters with yield obtained from the interactions of planting time and fungicide application frequency. The following model for factorial RCBD was used.

Model for the Experiment:

y_{ijk}= μ + αi+ βj+(αβ) ij+€ijk

i=1,2...Planting time,
j=1,2...Fungicide application frequency,
k=1,2...Number of replications.
Where, μ=the overall mean effects, αi=the effects of i^{th}level of planting time, i=1-4, βj=the effects of the j^{th}level of fungicide application frequency, j=1-4 (αβ), ij=the interaction effects between planting time and fungicide application frequency, €ijk=the random error compared for the whole factor, k=number of replications.

RESULTS AND DISCUSSION

Days to first disease symptom appearance (DDA)

The analysis of variance showed that the main factor planting time had significant effect ($P < 0.05$) on days to first disease symptom. The maximum number of days to first disease symptom appearance (28.17) was recorded from early planted treatments on 15th of June. On the other hand, the minimum number of days to first disease symptom appearance (14) was recorded from treatments planted on 30th of July 2017 (Figure 1). This might be due to the small amount of rainfall (64.2 mm) in June with low relative humidity (44.2%) which did not favor the onset of the disease. But, as the rainfall progressed in the later month (July), the disease could appear earlier. In agreement with studies of Muhinyuza et al. (2007) the conducive weather condition for late blight was during the season having 145.5 mm month^{-1} rainfall with a relative humidity around 90% and temperature of 15 to 20°C.

Disease incidence

The main factors, planting time and fungicide application frequency and their interaction effect on disease incidence were highly significant *($P < 0.01$)*. The highest disease incidence (83.33%) was observed on treatments planted on 30th of June and non-fungicide applied treatments and this value was not statistically significant with treatments planted on 15th of June (82%) and July (79.67%) and non-fungicide applied treatments (Table 1). On the other hand, the minimum disease incidence (28.33%) was recorded on treatments planted on 30th of June and 15th of July and three times fungicide applied which was statistically not significant with treatments planted on 15th and 30th of July and twice fungicide applied and also with treatments planted on 30th of July and three times fungicide applied treatments (Table 1). The minimum disease incidence could be due to positive interaction and complementary effect between planting time and fungicide application frequency in affecting disease incidence, while the highest disease incidence on treatments planted on 15th of June and non-fungicide applied treatments was probably due to absence of fungicide application and favorable weather condition like rain fall, temperature and relative humidity for the disease development. Disease incidence depends on meteorological conditions, cultivars susceptibility to potato late blight, and growth stage of the potato during disease attack (Razukas et al*.,* 2008). In agreement with this experiment, Muhinyuza et al. (2007) observed the initial sources of infection owing to the absence of suitable rainfall and temperature for late blight development.

Percent severity index

Planting time and fungicide application frequency were highly significant *($P<0.01$)* and the interaction effect between the treatments also had a significant effect *($P<0.05$)* on percent severity index. The highest percent severity index (43.83%) was recorded from treatments planted on 15th of June and non-fungicide applied treatments and this value was statistically similar with results obtained from treatments planted on 15th and 30th of July and June and non-fungicide applied treatments. On the other hand the lowest percent severity index (24.69%) was registered in the lately planted treatments on 30th of July and twice fungicide applied treatments which was statistically similar with value recorded from treatments planted on 15th of July and twice and three times fungicide applied treatments and also from experimental plots planted on 30th July and once and three times fungicide applied (Table 1). Delay in planting time from early planting on 15th of June to 30th of July reduced percent severity index by 23.55%. This might be due to weather condition during early planting (June 15) that favors percent severity in turn can result in more foliage and leaf area affected by late blight. Likewise, increasing application frequencies of fungicide reduced percent severity index. Application frequencies of fungicide once, twice and three times, reduced percent severity index by 11.99, 22.36 and 32.32%, respectively as compared with the control (non-fungicide applied). Since there was no significant difference among once and twice and twice and three times fungicide application frequencies, the lower application frequencies are preferred to obtain a satisfactory level of control of the disease. Shtienberg et al*.* (1994) reported the effortsmade to reduce the amount of fungicide used in late blight management considering the environment, public health, and fungicide resistance.

Area under disease progress curve (AUDPC)

Analysis of data for area under disease progress curve (AUDPC) revealed significant *($P<0.05$)* differences among the treatment combinations of planting time and fungicide application frequency. The main factors planting time and fungicide application frequency also had highly significant *($P<0.01$)* effect on AUDPC. The highest AUDPC value (1424.5) was recorded from 30th of June planting and non-fungicide applied treatments which was statistically similar with 15th of June and 15th of July plantings and non-fungicide applied treatments (1411.67 and 1271.67, respectively). In contrast, the smallest AUDPC value (275.33) was recorded from 30th of July planting and twice fungicide applied treatments. This was statistically similar with the result obtained from late planting on 30th of July and once and three times fungicide application, 15th of July planting and twice and three times fungicide application and 30th of June planting and three times fungicide applied treatments. The highest value of AUDPC indicated the highest disease development on potato plants that were not treated with fungicide and due to the disease favored by weather

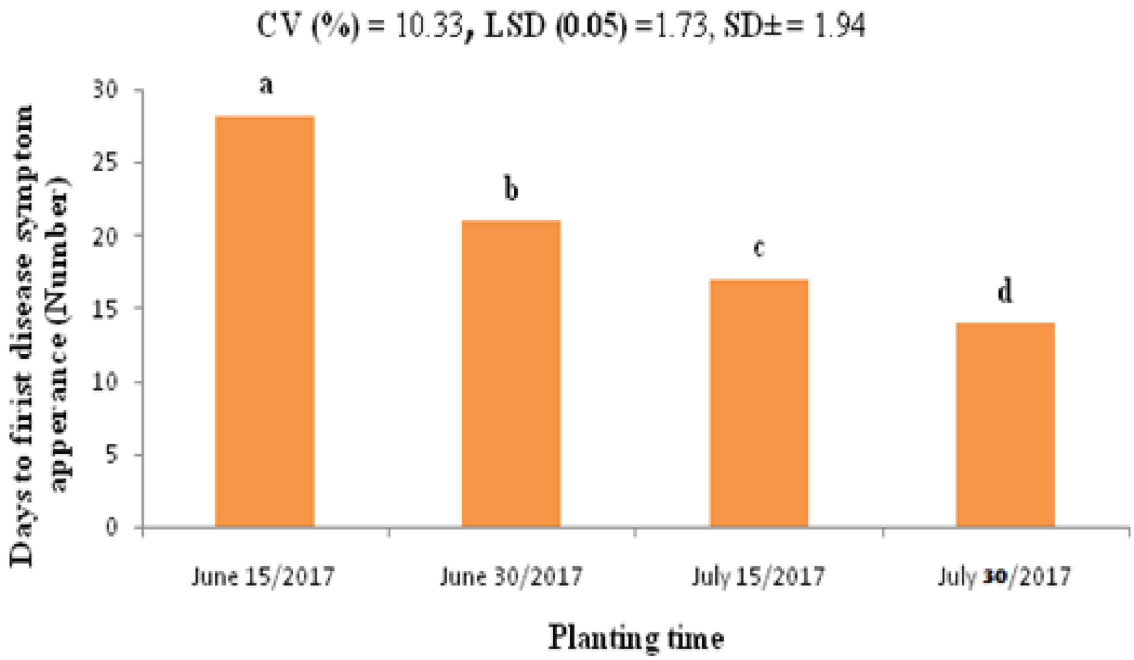

Figure 1. Effects of planting time on days to first disease symptom appearance (means followed by the same letter per column are not significantly different at $p > 0.05$).

Table 1. Disease incidence, percent severity index and AUDPC as affected by the interaction effect of planting time and fungicide application frequency.

Pt	Faf	DI (%)	PSI (%)	AUDPC
1st planting	None	82.00^{a}	43.83^{a}	1411.67^{a}
	Once	59.00^{c}	39.51^{bc}	1067.50^{bc}
	Twice	55.00^{d}	37.04^{cd}	945.00^{cd}
	Three times	50.67^{e}	32.71^{ef}	711.67^{de}
2nd planting	None	83.33^{a}	43.21^{ab}	1424.50^{a}
	Once	55.33^{cd}	37.65^{cd}	772.33^{de}
	Twice	50.00^{e}	38.27^{c}	899.50^{cd}
	Three times	28.33^{h}	29.01^{fg}	372.17^{f}
3rd planting	None	79.67^{a}	43.82^{a}	1271.67^{ab}
	Once	38.67^{f}	33.95^{de}	647.50^{e}
	Twice	32.00^{gh}	27.78^{gh}	299.83^{f}
	Three times	28.33^{h}	25.93^{gh}	304.50^{f}
4th planting	None	67.00^{b}	37.04^{cd}	802.67^{de}
	Once	34.00^{g}	28.40^{gh}	371.00^{f}
	Twice	30.33^{gh}	24.69^{h}	275.33^{f}
	Three times	31.33^{gh}	25.31^{gh}	325.83^{f}
LSD (0.05)		3.99	4.15	123.53
SD±		2.33	2.23	181.91
CV%		4.67	7.46	19.98

Means followed by the same letter per column are not significantly different at $p > 0.05$. Pt= Planting time, Faf= Fungicide application frequency, DI = Disease incidence and PSI = Percent severity index.

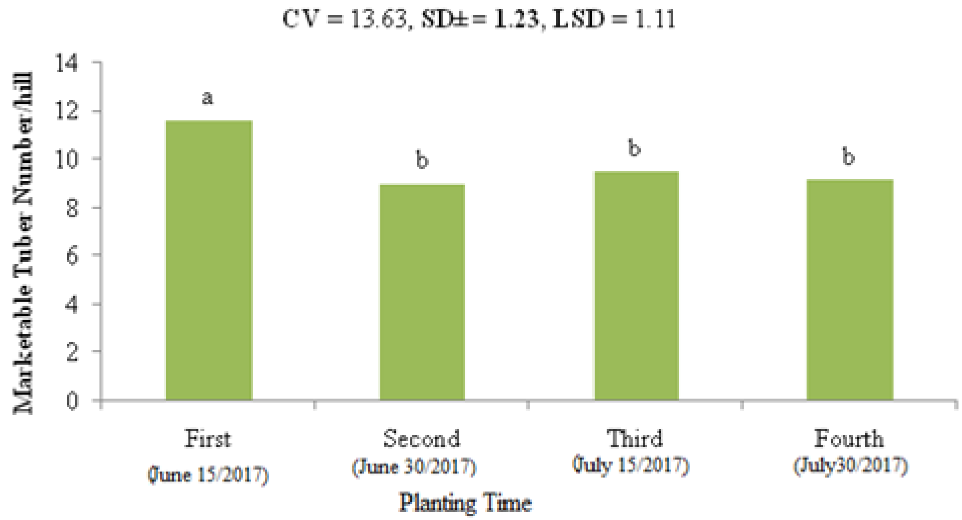

Figure 2. Number of marketable tubersper hill as influenced by planting time (means followed by the same letter per column are not significantly different at p > 0.05).

condition like rainfall, temperature and relative humidity of the study area. While, the smallest value might be due to the effect of fungicide on controlling the severity of late blight and the environmental factors which did not favor disease development. This is in agreement with Razukas et al*.* (2008) who stated that the optimal conditions for late blight spread are higher relative humidity (>75%) and 13°C temperature.

Number of marketable tubers per hill

Number of marketable tubers per hill was highly significantly (*P< 0.01*) affected by planting time but not affected (*P>0.05*) by fungicide application frequency and the interaction effect of planting time and fungicide application frequency. The highest average number of tubers per hill (11.61) was produced by treatments planted on June 15, while the smallest number of tubers per hill (8.97) was obtained from treatments planted on June 30 which was statistically similar with that of July 15 and July 30 plantings (Figure 2). The highest number of marketable tubers per hill at first planting on 15th of June might be due to favorable weather condition (well distributed rain fall, optimum temperature and relative humidity).However, it decreased in the late plantings probably due to unsuitable environmental conditions like low rainfall and relatively high temperature during potato growing season of the study area at the time of the experimental period.

Number of unmarketable tubers per hill

Analysis of variance on number of unmarketable tubers per hill revealed highly significant *(P < 0.01)* differences by planting time, fungicide application frequency and the interaction effect between planting time and fungicide application frequency. The highest number of unmarketable tubers (4.89) was recorded from plots planted on 30th of June and non-fungicide applied treatment which was statistically similar with result obtained from treatments planted on 15th of July and once fungicide applied treatment (Figure 3). On the other hand, the smallest number of unmarketable tubers per hill (1.22) was recorded from treatments planted on 15th of June and once fungicide applied treatments. This was statistically similar with results obtained from treatments planted on 15th of June and July and twice fungicide applied (Figure 3).

The observed maximum number of unmarketable tubers might be due to absence of fungicide application and weather condition that favor late blight disease which in return affected number of unmarketable tubers. In addition to disease effect, number of unmarketable tubers was influenced by the under sized number of tubers (Figure 3). More number of under sized tubers (<25 mm) as well as varietal character and adaptability orestablishment effect of other growth attributes (Kumar et al., 2007) increase number of unmarketable tubers. Stem number and plant height can strongly influence unmarketable tubers of many potato cultivars (Arsenault and Christie, 2004).

Total number of tubers per hill

Total number of tubers per hill was statistically affected (*P<0.05*) by planting time from 15th of June to 30th of July, but not influenced by fungicide application frequencies

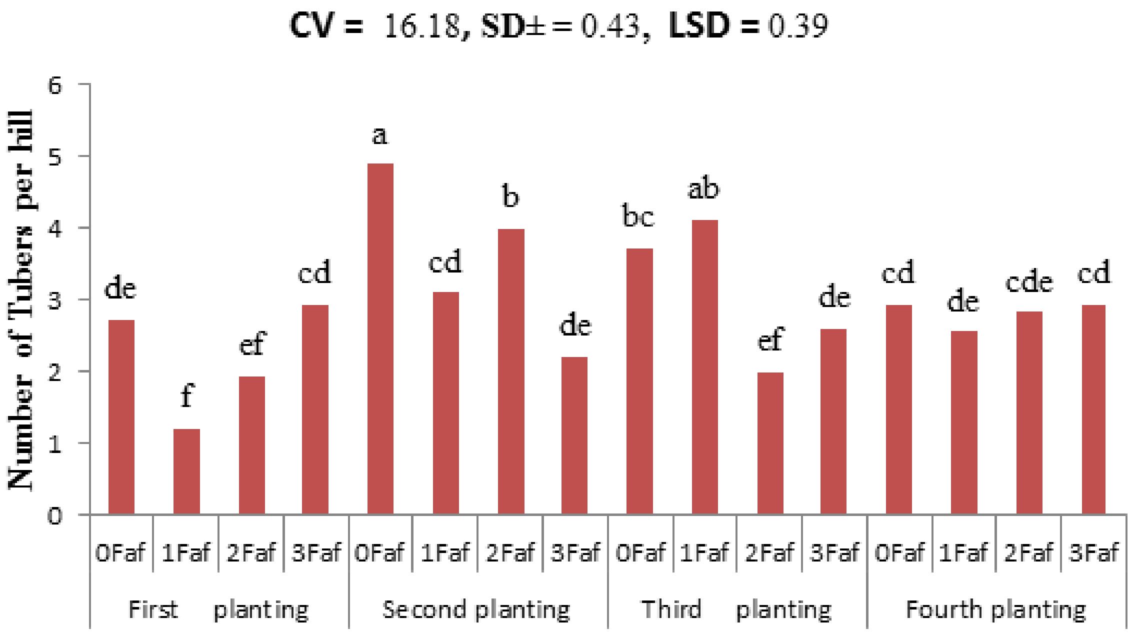

Figure 3. Number of unmarketable tubers per hill as influenced by the interaction effect between planting time and fungicide application frequency. Pt = Planting time and Faf = Fungicide application frequency (Means followed by the same letter per column are not significantly different at $p > 0.05$).

and the interaction effect between treatments. The highest total number of tubers per hill (13.81) was recorded from treatments planted on 15th of June while, the smallest total number of tubers per hill (11.98) obtained from late planting on 30th of July which was statistically similar with total tuber number per hill recorded from treatments planted on 30th of June and 15th of July (Figure 4). Total number of tubers per hill of first planted treatments on 15th of June increased by 8.5, 8.7 and 13.3% from treatments planted on 30th of June, 15th and 30th of July, respectively (Figure 4). This is probably because of optimal environmental condition like temperature and rainfall for plant growth during the first few weeks of crop development reflected in good tuber count. The potential tuber number that can be successfully produced by a plant varies with the genotype, physiological age of seed, number of stems per hill (stem population) and environmental conditions during the initiation phase of growth (Kleinkopf et al., 2003; Mihovilovich et al., 2009).

Even though the environmental condition was favorable, potato planted on 30th of July produced lower total tuber number than the early planted plants on 15th of June. Decrease in tuber number from late planted treatments on 30th of July was probably because of unsuitable environmental condition like low rainfall and relatively high temperature during potato vegetative growth stage. The results obtained are fairly supported by the findings of Levy and Veilleux (2007), who investigated the response of six potato cultivars to water stress under high ambient temperature and observed that tuber number was adversely affected by drought occurring in the middle and late parts of the season. This corresponds to the stages of growth of tuber initiation and bulking. In addition to this it might be related with the limited number of main stem at late planting due to using older seed. Hassanpanah et al. (2009); Firman and Daniels (2011) and Khan et al. (2011) have reported similar trends of producing lower total tuber number per plant at late plantings of main cropping season.

Average tuber weight

Planting time, fungicide application frequency and the interaction effect between planting time and fungicide application frequency were highly significant *($P < 0.01$)* for average tuber weight. The highest average tuber weight (80.82 g) was produced by treatments planted on 15th of June and twice fungicide application while, the smallest average tuber weight (38.58 g) was obtained from treatments planted on 30th of July and non-fungicide applied (Table 2). The achievement of producing the heaviest tubers in the earlier planted potato might be due to the favorable soil moisture and temperature for tuber growth with early planting in June than late planting in July under rain-fed condition. This is in agreement with results of Yenagi et al. (2004) who stated that potato grown on favorable soil moisture and temperature gives better tuber weight.

Generally when there is large number of stems/hill there will be more number of tubers/hill and when there

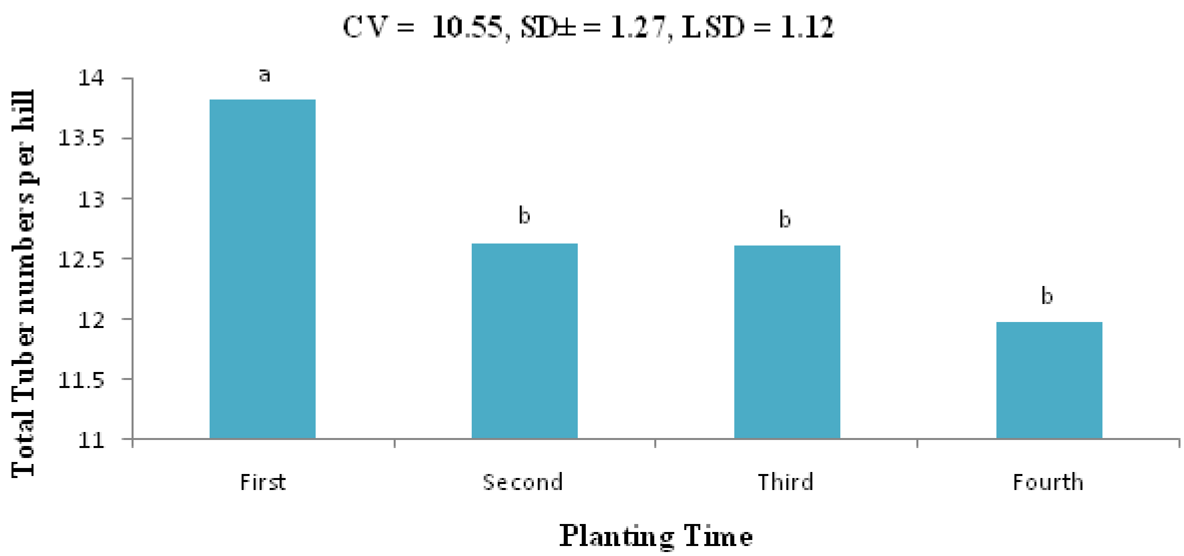

Figure 4. Total number of tubers as influenced by planting time (means followed by the same letter per column are not significantly different at p > 0.05).

are few numbers of tuber /hill it is expected to have high average tuber weight; however in present study in delayed plantings (July 30) plants which developed smaller number of stems/hill produced lower number of tubers per hill and low average tuber weight. This could be attributed to water and temperature stress that prevailed at tuber initiation up to bulking stages of potato planted in delayed plantings. Water and temperature stress during vegetative and tuber initiation growth stages have also been shown to decrease the number of tubers set per plant (King et al*.,* 2003; Modisane, 2007)**.** After initiation, both the weight and volume of the tubers increase almost linearly, but either water or temperature stress interrupt this process and often result in small, misshapen and irregular shaped tubers (King et al*.,* 2003; Levy and Veilleux, 2007). Firman and Daniels (2011) and Khan et al. (2011) also observed the same phenomenon of producing low number of tubers and low average tuber weight due to unsuitable environmental condition in delayed plantings.

Marketable tuber yield

Planting time, fungicide application frequency and their interaction had highly significant effect (*P < 0.01*) on marketable tuber yield. The highest marketable tuber yield (43.20 ton ha^{-1}) was produced from treatments planted on 15th of June and twice fungicide applied treatments which was statistically similar with yield obtained from treatments planted on 15th of June in combination with three times fungicide application. On the other hand the lowest marketable yield (22.77 ton ha^{-1}) was obtained from treatments planted on 30th of July and non-fungicide applied which was not statistically different from treatments planted on 30th of June and 15th of July and non-fungicide applied, 15th of July and once fungicide applied, 30th of June and three times fungicide applied and 30th of July and twice fungicide applied (Table 2). The variation might be attributed to different effect of weather condition like soil moisture, temperature and relative humidity at different planting time from early June to late July on tuber bulking and less disease progress due to fungicide application. This result is supported by Levy and Veilleux (2007) who reported that, duration of tuber bulking depends on environmental conditions.

In all treatments used, the trend of earlier planting in mid-June gave higher marketable yield; this could be explained by the longer growing period and favorable environmental factors. Tubers planted at earlier dates on June 15 and June 30 received more time of optimum moisture and temperatures which resulted in higher marketable tuber yield than the late plantings of July 15 and July 30. The phenomenon is well supported by Yenagi et al. (2004) and Khan et al*.* (2011) who reported reduced marketable yield was obtained from delay in planting due to unfavorable climatic condition for tuber growth. In the present study early plantings provided maximum period of optimal temperature and rainfall for crop development in combination with fungicide application. This resulted in excellent foliage growth and longer maturation time with improved photosynthesis which ultimately helped in increasing the size of tubers. The result is attributed to the delay in the onset of the disease on early-planted potatoes on 15th and 30th of June compared to the late-planted ones on 15th and 30th of July. Moreover, there was optimum rainfall for better

Table 2. Interaction effects of planting time and fungicide application frequency on yield and yield components of potato.

Pt	Faf	MTY(t/ha)	UMTY(t/ha)	TTY(t/ha)	ATW(g/tuber)
1st planting	None	28.30[cd]	4.43[ab]	32.73[cd]	66.80[c]
	Once	36.90[b]	2.13[e]	39.03[b]	80.82[a]
	Twice	43.20[a]	2.03[e]	45.23[a]	76.55[b]
	Three times	41.67[a]	2.47[cde]	44.10[a]	56.71[ef]
2nd planting	None	24.07[ef]	5.33[a]	29.40[de]	67.01[c]
	Once	30.43[c]	3.70[bcd]	34.13[c]	73.92[b]
	Twice	27.83[cde]	3.63[bcd]	31.47[cd]	74.16[b]
	Three times	25.37[def]	1.40[e]	26.80[e]	66.84[c]
3rd planting	None	25.60[def]	4.23[ab]	29.83[cde]	51.07[g]
	Once	26.73[cdef]	2.50[cde]	29.23[de]	57.49[ef]
	Twice	27.90[cde]	2.40[de]	30.30[cde]	58.53[de]
	Three times	29.43[cd]	5.13[a]	34.30[c]	65.05[d]
4th planting	None	22.77[f]	3.77[bc]	26.53[e]	38.85[i]
	Once	27.20[cde]	3.53[bcd]	30.73[cde]	54.75[f]
	Twice	26.33[cdef]	4.17[ab]	30.50[cde]	42.39[h]
	Three times	27.10[cde]	3.50[bcd]	30.60[cde]	51.09[g]
LSD (0.05)		4.21	1.33	4.57	2.95
SD±		2.37	0.74	2.57	1.67
CV%		8.60	23.51	8.37	2.90

Means followed by the same letter per column are not significantly different at p > 0.05. ATW= average tuber weight; MTY= marketable tuber yield; UMTY= unmarketable tuber yield and TTY= total tuber yield.

crop performance in the early than the later plantings, which gave better growth conditions such that the crop completed tuber bulking before disease reached severe proportions. In agreement with a report by Kankwatsa et al*.* (2002) early planting at the time of rainfall onset contributed to the delay in disease development and consequently gave higher tuber yield than late planting.

Unmarketable tuber yield

Analyzed data of unmarketable tuber yield showed highly significant (*P < 0.01)* difference for fungicide application frequency and the interaction effect between fungicide application frequency and significant (*P < 0.05)* difference for planting time. Higher unmarketable yield (5.33 ton ha^{-1}) was registered by treatments planted on 30th of June and non-fungicide applied which was statistically not significant with result obtained from treatments planted on 15th of June and July and non-fungicide applied, 15th and 30th of July and three times and twice fungicide applied (Table 2). While, the low unmarketable yield (1.4 ton ha^{-1}) was produced by treatments planted on 30th June and three times fungicide applied which was statistically not significant with treatments planted on 15th of June and once, twice and three times fungicide applied (2.13, 2.03 and 2.47 ton ha^{-1}, respectively) and with treatments planted on 15th of July and once and twice fungicide applied (2.4 and 2.5 ton ha^{-1} respectively). The observed maximum unmarketable yield might be due to presence of late blight disease as well as more number of under sized tubers (< 25 mm) establishment due to effect of other growth attributes like shortage of soil moisture and high temperature. This result is in agreement with result reported by Kumar et al. (2007) who stated that tuber size was affected by environmental factors and late blight influence on potato leaves. Stem number and plant height can strongly influence non-marketable yield of many potato cultivars (Arsenault and Christie, 2004).

Results of this study revealed that the delay in planting (late July) resulted in higher percentage of under sized tubers (< 25 mm) as a result of which high unmarketable tuber number lead to higher unmarketable tuber yield. Moreover, higher numbers of under sized and malformed tubers were observed in late plantings. When high temperature stress is combined with drought stress under field conditions, tuber malformation and tuber sprouting are aggravated (Levy, 1986). High temperatures during tuber maturation interfere with the onset of tuber dormancy; affect tuber size, shorten their rest period, or even release the inhibition of tuber buds, resulting in pre-harvest sprouting (Levy and Veilleux, 2007).

Total tuber yield

Planting time, fungicide application frequency and their interaction effect were highly significant (*P < 0.01*) on total tuber yield. The highest total tuber yield (45.23 ton ha^{-1}) was produced by treatments planted on 15^{th} of June and twice fungicide application which was not statistically significant with total yield obtained from treatments planted on 15^{th} of June and three times fungicide application. On the other hand, the smallest total tuber yield (26.53 ton ha^{-1}) was recorded from treatments planted on 30^{th} of July and non-fungicide applied treatments. This result was statistically similar with total tuber yield obtained from treatments plated on 30^{th} of June and three times and non-fungicide applied treatments, with results obtained from treatments planted on 15^{th} of July and twice, once and non-fungicide applied and with treatments planted on 30^{th} of July and once, twice and three times fungicide applied. The higher total yield in early planted treatments in June might be due to favorable weather condition and the ability of the variety to produce faster and early top growth followed by formation of large sized and higher number of tubers per plant. This goes along with the conclusions of Levy (1982) that, the highest tuber yield produced due to favorable environmental factors during tuber imitation and tuberization period.

Potato planted at earlier dates in June showed the highest number of tubers per plant, and highest average tuber weight and consequently the highest total yield. It is in agreement with the report of Abubaker et al*.* (2011) who observed the highest total yield on potato having higher tuber number. Mehdi et al. (2008) also concluded the increase in yield was mainly on account of higher number of tubers per plant and tuber size. Tubers planted at earlier dates of June received more time of optimum moisture and temperatures than the late planting in July, which resulted in higher total tuber yield. The results are well supported by Yenagi et al. (2004) and Khan et al*.* (2011) who recorded higher total tuber yield with early planting at the time of onset of rain fall due to favorable weather condition for tuber growth. In late planting, the total yield was less due to water stress usually causes early senescence of leaves there by shortening the growing season, resulting in lower tuber yield (Shiri-e-Janagard et al., 2009). Under Ethiopian condition Tesfaye et al*.* (2006) also observed decreased yield in late plantings due to higher disease incidence in late planting. In contrast, higher late blight incidence was observed on early planted (mid-June) potato in this experiment; but higher tuber yield was recorded compared to the late planting in late July. This result was due to the fact that plants could escape the sever infestation before the disease becomes sever which is supported by Struik (2010) that the host plant escape late blight by physiological strategies.

Conclusion

The highest value of percent severity index (43.82%), disease incidence (82.33%) and area under disease progress curve (1424.5) were observed on treatments planted on 15^{th} and 30^{th} of June and non-fungicide applied treatments respectively. Days to first disease symptom appearance decreased from early planting in June to late planting in July (28, 21, 17 and 13 days, respectively).

The maximum marketable tuber yield (43.20 ton ha^{-1}) was obtained from treatments planted on 15^{th} of June and twice fungicide application and the highest total number of tubers per hill (13.81) was recorded from treatment planted on 15^{th} of June.

In general, the best management of late blight was observed on early planted (15^{th} of June) and twice fungicide applied treatments. According to the result of this study, integration of appropriate planting time and reduced frequency of fungicide application is critical in the management of potato late blight. This not only increases potato productivity but also helps to minimize environmental pollution and cost of fungicide.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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