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African Journal of Plant Science

Full Length Research Paper

Plant disease forecast and modern dynamism in black pod disease management in Nigeria

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Black pod disease (BPD) is reputed for its regular occurrence in Africa and around the world with high propensity for massive destruction of cocoa pods in the field and total yield loss per season if proper management strategies are not applied. This research was designed to provide useful and timely information on BPD outbreak, its intensity and specific areas expected to be massively affected by the disease in Nigeria. Twelve (12) research locations were mapped out from four important cocoa producing states in Southwest, Nigeria for BPD assessment and forecast. The BPD forecast system "ETAPOD" accurately predicted BPD outbreak in Ondo (Ọwenà and Wáàsimi) and Osun (Adaàgbà, Iyánfọwọrọgi, and Owódé-Igàngán), but it failed to give accurate predictions for Ogun (Ọbáfémi-Owódé) and Oyo (Mòyè village, Dáagi-Lógbà and Olórò village) states. The performance of ETAPOD was greatly affected by the credibility of the data fed into the system, this can be improved on. ETAPOD predicted BPD outbreak closely within the range of natural BPD occurrences.

Key words: Disease forecast, black pod disease (BPD) outbreak, total yield loss, ETAPOD, data credibility.

INTRODUCTION

Black pod disease (BPD) associated with symptoms like leaf blight, pod rot, stem canker and death of the entire *Theobroma cacao* plant was reported by Opoku et al. (2000) as one of the most influential diseases of cocoa. Akrofi (2015) reported that the disease occurred annually with high propensity for massive cocoa pod destruction and total yield loss if proper management strategies were not applied. Oluyole and Lawal (2008) reported an estimated average occurrence of the disease in several parts of West Africa as 40% and up to 90% in certain places in Nigeria. The extent of damage caused by BPD infections had been reported by Kudjordjie (2015) to be more in West Africa than in any other cocoa growing regions of the world.

This research was designed to provide useful and timely information on BPD outbreak, its intensity and specific areas expected to be greatly affected by the disease in Nigeria. This will eradicate doubts and uncertainty in the minds of investors on their choice of investment(s) made in cocoa production nationwide, eradicate fungicide misuse, increase cocoa production, reduce the risk of chemical poisoning by discouraging indiscriminate use of fungicide which will further ensure the availability of disease-free and non-toxic raw materials for cocoa processing industries; increasing farmers' profit, foreign exchange values and internally generated revenue (IGR) from the sales of cocoa beans. The forecast system "ETAPOD" is user friendly, easy to interpret, highly

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Table 1. The description of the research locations.

Post	Location	LGA	State	Latitude	Longitude	Altitude (m)	Farm size (m^2)
1	Ọbáfémi-Owódé	Ọbáfémi-Owódé	Ogun	7°08'30.37"N	3°25'56.71"E	187	10,000
2	Ọbáfémi-Owódé	Ọbáfémi-Owódé	Ogun	7°08'30.32"N	3°25'56.73"E	192	10,000
3	Adaàgbà	Ife South	Osun	7°22'13.80"N	4°33'34.42"E	262	40,000
4	Owódé-Igàngán	Atàkunmosá East	Osun	7°29'59.99"N	4°48'59.99"E	276	50,000
5	Iyánfowórogi	Ife South	Osun	7°21'55.22"N	4°34'16.54"E	259	20,000
6	Owódé-Igàngán	Atàkunmosá East	Osun	7°29'53.45"N	4°48'59.01"E	282	50,000
7	Òwenà	Ondo East	Ondo	7°12'11.52"N	5°00'55.76"E	289	10,000
8	Òwenà	Ondo East	Ondo	7°12'11.50"N	5°00'55.76"E	291	10,000
9	Wáàsimi	Ondo East	Ondo	7°10'42.78"N	4°59'31.34"E	249	30,000
10	Mòyè village	Ọnà-Arà	Oyo	7°18'54.54"N	4°01'09.34"E	205	20,000
11	Dáagi-Lógbà	Iddo	Oyo	7°20'47.58"N	3°44'30.59"E	174	20,000
12	Olórò village	Ọnà-Arà	Oyo	7°20'44.00"N	3°59'34.00"E	179	10,000

Source: BPD assessment (2015/2016) © Etaware and Adedeji (2018).

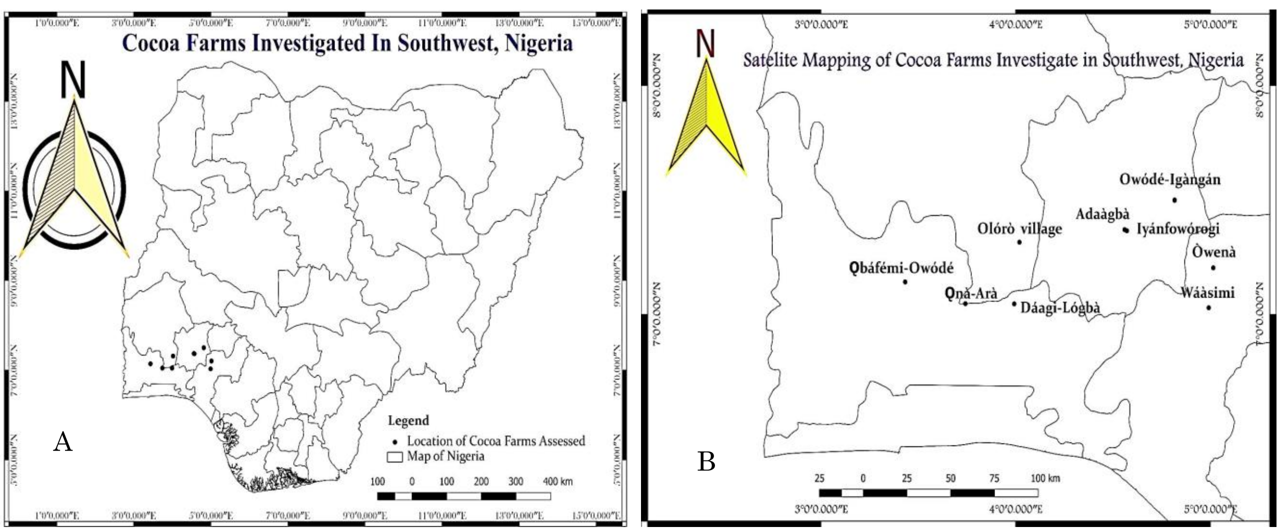


Figure 1. The research locations: (A) an overview; (B) a cross section view.

proficient, reliable, and cost efficient, designed for monthly and annual BPD predictions. The installation and implementation of ETAPOD will help promote a disease free, clean and healthy environment.

MATERIALS AND METHODS

Research locations

Twelve (12) research locations were mapped out from four important cocoa producing states in Southwest, Nigeria. The research locations are shown in Table 1 and their geographical positions shown in Figure 1.

Epidemiological data

The disease status (BPD incidence and severity) from the earmarked research locations were obtained from Etaware and Adedeji (2018).

Weather data

Weather data used for BPD prediction was collected from the National Bureau of Statistics (NBS) Ibadan and Nigerian Meteorological Station (Nimet).

BPD Prediction

The forecast system used for BPD prediction (ETAPOD) was developed by Etaware et al. (2018).

Data analysis

The geospatial data collected using Garmin eTrex® 10 GPS tracker

Ondo	ETAPOD							
LGA								
Town								
	Black pod disease warning system for the Southwest of Nigeria							
2015/2016			Rainfall (mm)		Rel. Humidity (%)		Temperature (°C)	Black Pod Occurrence (%)
January	20.4	0.004	6.50	0.27	35.8	0.51	18.4	-1.3964
February	20.4	0.004	35.6	0.27	35.4	0.51	21.5	-0.0397199999999991
March	20.4	0.004	84.5	0.27	49.8	0.51	22.8	4.31544
April	20.4	0.004	173	0.27	59.2	0.51	22.7	6.4792
May	20.4	0.004	168	0.27	67.2	0.51	22.6	8.5776
June	20.4	0.004	199	0.27	70.4	0.51	22.0	9.0524
July	20.4	0.004	313	0.27	82.6	0.51	21.2	11.4824
August	20.4	0.004	208	0.27	75.8	0.51	21.6	10.2602
September	20.4	0.004	255	0.27	75.0	0.51	22.1	10.0908
October	20.4	0.004	125	0.27	67.2	0.51	21.4	8.1682
November	20.4	0.004	25.7	0.27	52.4	0.51	21.3	4.49784
December	20.4	0.004	2.08	0.27	40.2	0.51	20.2	0.75788
					Total Annual Occurrence (>PPT)			72.24584
					Average Annual Black pod Disease Occurrence			6.0 %

Figure 2. Simulated BPD outbreak values for Ondo (2015/2016).

Osun	ETAPOD							
LGA								
Town								
	Black pod disease warning system for the Southwest of Nigeria							
2015/2016			Rainfall (mm)		Rel. Humidity (%)		Temperature (°C)	Black Pod Occurrence (%)
January	20.4	0.004	0.42	0.27	35.2	0.51	21.46	0.0469200000000001
February	20.4	0.004	41.4	0.27	36.2	0.51	23.62	1.25452
March	20.4	0.004	63.2	0.27	48.6	0.51	23.96	4.68864
April	20.4	0.004	101	0.27	57.8	0.51	23.68	6.87888
May	20.4	0.004	159	0.27	66.2	0.51	23.14	8.6394
June	20.4	0.004	168	0.27	69.8	0.51	22.86	9.4326
July	20.4	0.004	210	0.27	80.8	0.51	22.04	11.8164
August	20.4	0.004	136	0.27	74.4	0.51	21.96	10.3436
September	20.4	0.004	149	0.27	73.0	0.51	22.64	10.2588
October	20.4	0.004	163	0.27	65.0	0.51	22.16	7.79856
November	20.4	0.004	30.7	0.27	52.0	0.51	22.40	4.94104
December	20.4	0.004	14.9	0.27	41.2	0.51	21.58	1.67004
					Total Annual Occurrence (>PPT)			77.7694
					Average Annual Black pod Disease Occurrence			6.5 %

Figure 3. Simulated BPD outbreak values for Osun (2015/2016).

were analysed and positioned on the map using the quantum geographic information system (QGIS 2.18.3) incorporated with GRASS 7.2.0 functions for optimization. The analysis of variance was carried out using COSTAT 6.451 software and homogeneity of means determined using Duncan Multiple Range Test (DMRT).

RESULTS

ETAPOD simulated BPD outbreak (ESBO) versus real life BPD outbreak (RLBO)

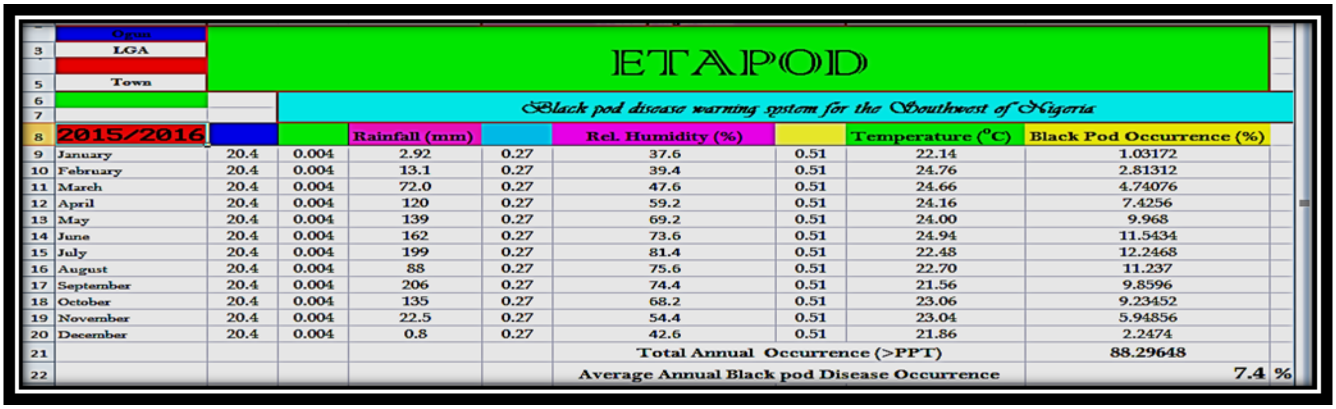
ETAPOD simulated BPD outbreak was 9.05% in Ondo (RLBO: 9.5%), 9.43% in Osun (RLBO: 9.0%), 11.5% in Ogun (RLBO: 0.0%), and 9.43% in Oyo (RLBO: 0.0%) in June 2015. In July, ESBO was 11.5% in Ondo (RLBO: 18.0%), 11.8% in Osun (RLBO: 13.5%), 12.2% in Ogun (RLBO: 0.0%), and 11.8% in Oyo (RLBO: 6.0%). In August, ESBO was 10.3% in Ondo (RLBO: 26.5%), 10.3% in Osun (RLBO: 8.0%), 11.2% in Ogun (RLBO: 3.0%), and 10.4% in Oyo (RLBO: 16.0%). In September, ESBO was 10.1% in Ondo (RLO: 11.0%), 10.3% in Osun (RLBO: 11.5%), 9.86% in Ogun (RLBO: 15.0%), and 9.98% in Oyo (RLBO: 14.0%). In October, ESBO was 8.17% in Ondo (RLBO: 5.0%), 7.8% in Osun (RLBO: 10.0%), 9.23% in Ogun (RLBO: 22.0%), and 7.80% in Oyo (RLBO: 0.0%), respectively (Figures 2, 3, 4 and 5 and Table 2). The comparison was based on the optimum cocoa production period (July-August) to October where most of the pods are harvested from the field.

The difference between ESBO and RLBO values in Ogun, Ondo, Osun and Oyo

It was also shown that the difference between real life BPD occurrences and predicted values was-8.58%≤ Ondo≤16.2%, -7.14%≤Osun≤2.20%, -11.5%≤ Ogun ≤12.8% and -9.43%≤Oyo≤5.60%, respectively (Table 3).

The level of accuracy of ETAPOD

ETAPOD accurately predicted BPD outbreak for Ondo and Osun for the period of June 2015 to March 2016



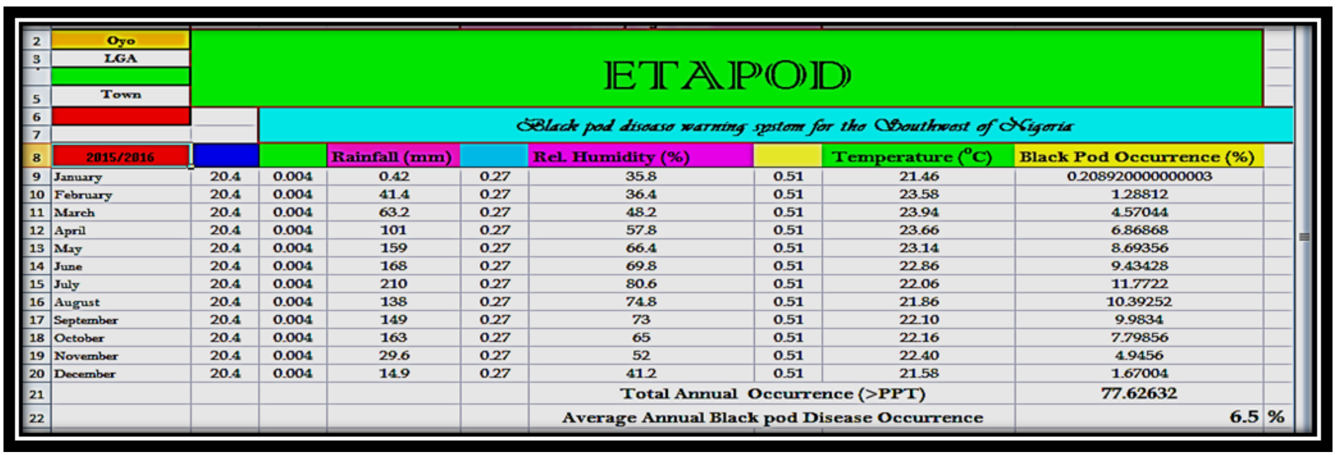
Ogun
LGA
Town

ETAPOD

Black pod disease warning system for the Southwest of Nigeria

2015/2016			Rainfall (mm)		Rel. Humidity (%)		Temperature (°C)	Black Pod Occurrence (%)
January	20.4	0.004	2.92	0.27	37.6	0.51	22.14	1.03172
February	20.4	0.004	13.1	0.27	39.4	0.51	24.76	2.81312
March	20.4	0.004	72.0	0.27	47.6	0.51	24.66	4.74076
April	20.4	0.004	120	0.27	59.2	0.51	24.16	7.4256
May	20.4	0.004	139	0.27	69.2	0.51	24.00	9.968
June	20.4	0.004	162	0.27	73.6	0.51	24.94	11.5434
July	20.4	0.004	199	0.27	81.4	0.51	22.48	12.2468
August	20.4	0.004	88	0.27	75.6	0.51	22.70	11.237
September	20.4	0.004	206	0.27	74.4	0.51	21.56	9.8596
October	20.4	0.004	135	0.27	68.2	0.51	23.06	9.23452
November	20.4	0.004	22.5	0.27	54.4	0.51	23.04	5.94856
December	20.4	0.004	0.8	0.27	42.6	0.51	21.86	2.2474
					Total Annual Occurrence (>PPT)			88.29648
					Average Annual Black pod Disease Occurrence			7.4 %

Figure 4. Simulated BPD outbreak values for Ogun (2015/2016).



Oyo
LGA
Town

ETAPOD

Black pod disease warning system for the Southwest of Nigeria

2015/2016			Rainfall (mm)		Rel. Humidity (%)		Temperature (°C)	Black Pod Occurrence (%)
January	20.4	0.004	0.42	0.27	35.8	0.51	21.46	0.208920000000003
February	20.4	0.004	41.4	0.27	36.4	0.51	23.58	1.28812
March	20.4	0.004	63.2	0.27	48.2	0.51	23.94	4.57044
April	20.4	0.004	101	0.27	57.8	0.51	23.66	6.86868
May	20.4	0.004	159	0.27	66.4	0.51	23.14	8.69356
June	20.4	0.004	168	0.27	69.8	0.51	22.86	9.43428
July	20.4	0.004	210	0.27	80.6	0.51	22.06	11.7722
August	20.4	0.004	138	0.27	74.8	0.51	21.86	10.39252
September	20.4	0.004	149	0.27	73	0.51	22.10	9.9834
October	20.4	0.004	163	0.27	65	0.51	22.16	7.79856
November	20.4	0.004	29.6	0.27	52	0.51	22.40	4.9456
December	20.4	0.004	14.9	0.27	41.2	0.51	21.58	1.67004
					Total Annual Occurrence (>PPT)			77.62632
					Average Annual Black pod Disease Occurrence			6.5 %

Figure 5. Simulated BPD values for Oyo (2015/2016).

Table 2. ETAPOD Simulated BPD Outbreak (SBO) versus Real Life BPD Occurrence (RLO).

Period	BPD Outbreak (%)							
	Ondo		Osun		Ogun		Oyo	
	RLBO	ESBO	RLBO	ESBO	RLBO	ESBO	RLBO	ESBO
05/2015	0.0	8.58	1.5	8.64	0.0	9.97	0.0	8.69
06/2015	9.5	9.05	9.0	9.43	0.0	11.5	0.0	9.43
07/2015	18.0	11.5	13.5	11.8	0.0	12.2	6.0	11.8
08/2015	26.5	10.3	8.0	10.3	3.0	11.2	16.0	10.4
09/2015	11.0	10.1	11.5	10.3	15.0	9.86	14.0	9.98
10/2015	5.0	8.17	10.0	7.80	22.0	9.23	0.0	7.80
11/2015	0.0	4.50	0.0	4.94	0.0	5.95	0.0	4.95
12/2015	0.0	0.76	0.0	1.67	0.0	2.25	0.0	1.67
01/2016	0.0	-1.40	0.0	0.05	0.0	1.03	0.0	0.21
02/2016	0.0	-0.04	0.0	1.25	0.0	2.81	0.0	1.29
03/2016	0.0	4.32	0.0	4.69	0.0	4.74	0.0	4.57
04/2016	0.0	6.48	0.0	6.88	0.0	7.43	0.0	6.87
05/2016	0.0	8.58	0.0	8.64	0.0	9.97	0.0	8.69

RLBO: Real Life BPD Occurrences; ESBO: ETAPOD simulated BPD outbreaks; BPD: black pod disease.

Table 3. The difference between ESBO and RLBO values in Ogun, Ondo, Osun and Oyo.

Period	Estimated difference (%)			
	Ondo	Osun	Ogun	Oyo
05/2015	-8.58	-7.14	-9.97	-8.69
06/2015	0.45	-0.43	-11.5	-9.43
07/2015	6.50	1.70	-12.2	-5.80
08/2015	16.2	-2.30	-8.20	5.60
09/2015	0.90	1.20	5.14	4.02
10/2015	-3.17	2.20	12.8	-7.80
11/2015	-4.50	-4.94	-5.95	-4.95
12/2015	-0.76	-1.67	-2.25	-1.67
01/2016	1.40	-0.05	-1.03	-0.21
02/2016	0.04	-1.25	-2.81	-1.29
03/2016	-4.32	-4.69	-4.74	-4.57
04/2016	-6.48	-6.88	-7.43	-6.87
05/2016	-8.58	-8.64	-9.97	-8.69

Table 4. The level of accuracy of ETAPOD.

Period	Ondo	Osun	Ogun	Oyo
05/2015	-	-	-	-
06/2015	+	-/+	-	-
07/2015	+	+	-	-
08/2015	+	-/+	-	+
09/2015	+	+	+	+
10/2015	-/+	+	+	-
11/2015	-/+	-/+	-	-/+
12/2015	-/+	-/+	-/+	-/+
01/2016	+	+	-/+	-/+
02/2016	+	-/+	-/+	-/+
03/2016	-/+	-/+	-/+	-/+
04/2016	-	-	-	-
05/2016	-	-	-	-

+ = Accurate Disease Prediction. -/+ = Error in disease prediction less than 5%. - = Error in disease prediction more than 5%

(Table 4). Although, the simulated BPD outbreak values from the forecast system was not 100% accurate for Ogun and Oyo, BPD predictions for August 2015 to March 2016 (Table 4) was within the range of real life occurrences for 2015/2016 cocoa production season in Nigeria.

The error of prediction for the developed BPD forecast model

The error in the predicted result from ETAPOD was estimated as follows: 0.20 (Ondo), 0.18 (Osun), 132.3 (Ogun), and 88 .92 (Oyo) in June 2015. 42.25 (Ondo), 2.89 (Osun), 148.8 (Ogun), and 33.64 (Oyo) in July; 262.4 (Ondo), 5.29 (Osun), 67.24 (Ogun), and 31.36 (Oyo) in August; 0.81 (Ondo), 1.44 (Osun), 26.42 (Ogun), and 16.16 (Oyo) in September; and 10.05 (Ondo), 4.84 (Osun), 163.8 (Ogun), and 60.84 (Oyo) in October 2015, respectively (Table 5).

DISCUSSION

ETAPOD was able to forecast BPD outbreak for the2015/2016 cocoa production season in Ogun, Ondo, Osun and Oyo states. ETAPOD accurately quantified BPD outbreaks in Ondo and Osun during the optimum season of cocoa production in Nigeria, but it failed to accurately predict the disease level for Ogun and Oyo.

Table 5. The error of prediction for the developed BPD forecast model.

Period	Error in prediction of black pod disease occurrence $[E= (Y-\hat{Y})^2]$			
	Ondo	Osun	Ogun	Oyo
05/2015	73.62	50.98	99.4	75.52
06/2015	0.20	0.18	132.3	88.92
07/2015	42.25	2.89	148.8	33.64
08/2015	262.4	5.29	67.24	31.36
09/2015	0.81	1.44	26.42	16.16
10/2015	10.05	4.84	163.8	60.84
11/2015	20.25	24.4	35.40	24.5
12/2015	0.58	2.79	5.06	2.79
01/2016	1.96	0.00	1.06	0.04
02/2016	0.00	1.56	7.90	1.66
03/2016	18.66	22.00	22.47	20.88
04/2016	41.99	47.33	55.20	47.20
05/2016	73.62	74.65	99.40	75.52

This was in agreement with the research of Luo (2008) who stated that no forecast system can be 100% accurate at all times and that the accuracy level of any forecast system depends on several factors such as the credibility of the weather data fed into the system, the user proficiency of the forecast system, program errors, etc., which can be improved with time. The study was solely concerned with the maximum (March – October) and optimum (July – August) season of cocoa production and as such BPD information generated from ETAPOD was solely validated for those periods. It is known in Ghana that primary infection of cocoa pods in the field usually occur around June, but the peak of BPD infection generally occurred between August and October (Opoku et al., 2000, 2007). Information on the period for possible BPD infection in the field is useful in determining the pattern of disease development. Such information could be an important tool for disease management. The environmental conditions immediately preceding the infection period must be favourable for BPD development to occur and this period can be targeted for disease management.

Conclusion

ETAPOD is a warning system developed to ameliorate the devastating effects of black pod disease pestilence in Nigeria, within Africa and around the world, by providing useful information on the occurrence and spread of the disease with a clear coverage on the areas under severe attack. ETAPOD is unique as it is not geographically bound and thus, can be manipulated to provide optimum results wherever it is needed. A qualitative and quantitative description of the disease pressure was the key factor to determining the prevalence and spread of black pod disease in this study.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Effects of rooting media and indole-3-butyric acid (IBA) concentration on rooting and shoot development of *Duranta erecta* tip cuttings

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***Duranta erecta* is popularly grown as an ornamental plant in tropical and semi-tropical gardens. Current demands for the shrub have prompted the need for effective propagation methods. In this study, the influence of indole-3butyric acid (IBA) hormone concentration and media on rooting of *D. erecta* propagated from tip cuttings under greenhouse conditions were investigated. IBA hormone was used in three concentrations (2500, 5000, and 7500 ppm) and 0 ppm was the control. The study consisted of three media types (river sand, pine bark, a mixture of peat and perlite at a 1:1 ratio). The experiment was arranged in a 3×4 factorial layout in Randomized Complete Block Design replicated 3 times. Cutting survival, root length and number, shoot length and number were analysed. There was no interaction (P>0.001) between IBA concentration and media for all the measured parameters. The results showed that the optimum concentration of IBA is 5000 ppm, beyond which were inhibitory in all parameters except on root length. Type of media influenced survival and shoot number with pine bark giving the highest but did not affect root number, root length and shoot number.**

Key words: *Duranta erecta*, rooting, cuttings, media, river sand, pinebark, peat-lite.

INTRODUCTION

Duranta erecta is a species of flowering shrub in the Verbenaceae family originally native to Central and South America and is popularly grown as an ornamental plant in tropical and semi-tropical gardens (Singh et al., 2014; Said, 2016). The shrub is native to Mexico, South America and the Caribbean (Okunlola, 2013). *D. erecta* plays a significant role in environmental beautification and management; making public parks, gardens and houses more conducive for relaxation and enjoyment as an ornamental plant (Day and Loveys, 1998; Said, 2016). *D. erecta* increases the economic value of a property if properly placed in a landscape it can provide practical solutions for physical site problems with their durable aesthetic satisfaction (Okunlola, 2013). The shrub offers

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a variety of noticeable effects such as screening, cooling, enhancement of architectural lines, enframement of views, soil erosion management, sun and wind control, sound deadening and horticultural focus (Okunlola, 2013). *D. erecta* is mainly propagated vegetatively from stem cuttings.

Although *D. erecta* can be traditionally propagated using stem cuttings without any manipulations, this method can improve rooting when rooting hormones are used to hasten root initiation (Leonardi et al., 2001). The rooting of cuttings depends on several factors which include the type of cutting, rooting media, the type and concentration of rooting hormone used (Yeshiwas et al., 2015; Akram et al., 2017) and thickness of cuttings (Aminah et al., 2006). Rooting media is considered an integral part of the propagation system, percentage rooting and the quality of the roots produced are directly influenced by the medium (Kumar et al., 2015). There is no standard media or mix for cuttings, hence the appropriateness of the medium depends on the species, the cutting type, the season, the propagation system used, the cost and availability of the medium (Sardoei, 2014). Different media vary in their water holding capacities and potential to physically support the cuttings (Kumar et al., 2015). The common media used are sand, pine bark and a mixture of peat and perlite (1:1) (Akram et al., 2017; Sardoei, 2014). Sand consists of small rock particles, 0.05 to 2.0 mm in diameter formed as a result of weathering of many rocks. Sand must be fumigated or pasteurized before use as it may contain weed seeds and various harmful pathogens. Sand contains virtually no mineral nutrients and has no buffering capacity or cation exchange capacity (CEC) (Hartmann et al., 2002). Peat consists of the remains of aquatic, marsh, bog, or swampy vegetation that was preserved under water in a partially decomposed state and is commonly used in mixes (Hartmann et al., 2002). The acidic nature of peat generally excludes pathogens, insects and weeds from growing.

Perlite is another growing media used in the propagation of plants. Perlite is a grey-white salicaceous material, of volcanic origin, is sterile as a result of the high temperature processing. It is essentially neutral with no buffering capacity, no CEC. Perlite is usually mixed with peat for propagation of cuttings (Dole and Gibson, 2006). Pinebark is a product of the shredded or pulverized softwood bark from pine which has a high moisture holding capacity 15 times its dry weight and is acidic (pH 3.2 - 4.5) and contains a small amount of nitrogen about 1% (Akwatulira et al., 2011).

Application of exogenous hormones such as indole-3-butyric acid (IBA) increases the rate of rooting, final rooting percentage and number of roots (Leakey et al., 1990; Pacurar et al., 2014). Synthetic indole-3-butyric acid (IBA) is closely related to the naturally occurring plant growth regulator in terms of structure and function (Pacurar et al., 2014; Wiesman et al., 1988); and the hormone IBA is used on many crops and ornamentals but mainly horticultural plants to promote rooting of cuttings (Gilani et al., 2019; Akram et al., 2017; Li et al., 2009). However, it was observed that higher doses in some species were not beneficial. For instance, IBA concentrations above 2500 ppm were inhibitory in *Rosmarinus officinalis* and 1500 ppm was inhibitory in *Aloysia triphylla* (Costa Junior et al., 2018). While in *Warburgia ugandensis* 8000 ppm was optimum (Akwatulira et al., 2011) and the same concentration was inhibitory in *Ulmus panifolia* (Griffin and Schroeder, 2004). Considering the variability, rooting is IBA sensitive depending with species (Daskalakis et al., 2018).

In the recent years, there has been an overwhelming demand and use of *D. erecta* as an ornamental decorative shrub in Zimbabwe. According to Harare City Parks Division Annual Report (2014), *Duranta* has gained a lot of popularity due to its demand as a hedge and is a feature of more than 80% of flower beds in the Central Business District (CBD). However, Nursery Annual Report (2014) cites that the demand of this shrub has resulted into serious population deteriorations. Given the central importance that *D. erecta* play in landscape design systems, it becomes imperative to identify least cost rooting media and hormone options for ornamental nurseries. Therefore, research on how to come up with quick and convenient methods of propagating *D. erecta* to meet the ever increasing demand is vital. One such potential alternative is the propagation of *D. erecta* stem cuttings using different media types and different IBA concentrations. Considering the economic importance of the *D. erecta* as well as its potential use as a key ornamental decorative shrub in Zimbabwe, the present study was undertaken to assess the productivity of *D. erecta* in response to different IBA concentrations and rooting media.

MATERIALS AND METHODS

Site description

The experiment was conducted at Harare City nursery (Hillside) in the eastern suburbs of Harare, Zimbabwe from March 2015 to May 2015. The station lies in Natural Region IIa of Zimbabwe's Agro-ecological Zones, characterized by an altitude of 1486 m above sea level, mean annual rainfall of 750 to 1000 mm and mean annual temperature of between 15 and 20°C. Harare has latitude of 17°.51` South and a longitude of 31°.04` East. The study area receives an average annual rainfall of 825 mm and daily temperatures range from 7 to 22°C in winter and 16 to 26°C in summer.

Cultural practices

Preparation of rooting media

Milled pine bark and river sand were prepared by pasteurization and fumigation, while peat and perlite (peat-lite) were mixed without manipulation. Sand was pasteurized for 30 min by heating over an open cast metal plate and cooled (Kester et al., 1990) while milled pine bark was fumigated with Dithane M45 at 2000 ppm.

The different rooting media were allocated to different pots which were all filled up to 90%.

Preparation of cuttings

Stem cuttings of approximately 10 cm in length consisting of two or more lateral buds were sequentially harvested from mature *D. erecta* plants specially managed as sources of cuttings. Material with flower buds was avoided. A total of 360 tip cuttings were collected from coppices of selected *D. erecta* plants from Florence Chilshom park populations in their habitat. Leaves at the basal end of the cuttings were removed while those at the top were retained. The cuttings were collected in the morning hours, and kept moist or cool at all times by placing in cool box. The selected cuttings were softwood obtained from young succulent stems with new growth.

The cut bases were dipped in water up to a length of one cm to avoid water loss and wilting (Kester et al., 1990). Indole-3-butyric acid ≥99% (T) Sigma-Aldrich, Saint Louis United States was used and mixed with talcum powder. To get the desired concentrations IBA was first dissolved in 30% ethanol then mixed with talcum powder to a slurry. The slurry mixture was gently dried evaporatively. The dried mix was the ground and sieved to fine powder. A concentration of 2500 ppm was prepared by mixing 2.5 g IBA with 97.5 g talcum powder, the same method was used for all the concentrations. For each cutting, the 5 mm basal end was dipped into the different concentrations for 10 s. Excess powder was tapped off the cuttings. Each set of IBA treated cuttings was inserted into each rooting media type and replicated 3 times. The cuttings were stuck in different rooting media deep enough to stand. The rooting media were then compacted around the bases of the cuttings (in order to give support), gently watered thoroughly to get rid of any remaining air pockets in the media. Each set of ten cuttings was allocated randomly to each pot. The cuttings were checked on a daily basis and any dead leaves were removed.

Irrigation management

The cuttings were planted in propagation pots placed in a raised bed, equipped with overhead small sprinklers. The sprinklers were operated twice daily, in the early morning and in the late afternoon, for a period of 15 min during each time.

Experimental design and treatments

The experiment was carried out under a controlled environment in a greenhouse. Each growing media (pine bark, river sand, peat-lite) was applied in the pots and placed randomly in a greenhouse. The experiment was laid in a 3×4 factorial experiment in a Randomized Completely Block Design (RCBD) with three replications. There were two factors viz; rooting media (three types; river sand, pine bark and peat-lite) and IBA concentrations (three levels 2500, 5000, and 7500 ppm). No hormone was applied in the control treatment.

Parameters measured

Classical growth analysis was conducted based on six measurements: number and length of roots, number and length of shoots and survival of cuttings (rooted and shooted) following a method by Yeboah et al. (2009). The cuttings were uprooted by gentle pulling after loosening the media in the pot to measure root length and root number. Root and shoot number were measured by counting, root and shoot length were measured using a string and a ruler. All data were collected after seven weeks of planting.

Data analysis

The collected data was analysed statistically by Analysis of Variance (ANOVA) using statistical package GENSTAT version 17.1. Differences among treatment means were compared using the least significant difference (LSD) at 1%. All count data was transformed by square root method in GENSTAT.

RESULTS

Effects of hormone concentration (IBA) on root number and root length of cuttings

IBA concentration significantly increased ($P<0.001$) root number. The highest average number of roots was recorded at 5000 ppm, followed by 2500 ppm which was not different from 7500 ppm and the control (Figure 1A). Cuttings grown with an IBA of 7500 ppm had the lowest average number of roots. Rooting hormone concentration influenced root length ($P<0.001$) (Figure 1B). With 5000 ppm giving higher root length than the control and 7500 ppm, however 5000 pm was not statistically different from 2500 ppm.

Effects of IBA concentration on shoot number and shoot length

IBA concentration of 5000 ppm had cuttings with the highest average shoot number ($P<0.001$) (Figure 2A). There were no differences on shoot number among the other three treatments (control, 2500 and 7500 ppm) (Figure 2A).

Significant variations ($P<0.001$) were obtained on shoot length. The longest shoots were recorded at 5000 ppm, followed by 7500 ppm which was not different from 2500 ppm (Figure 2B) and 2500 ppm was not different from the control.

Effects of IBA concentration on cutting survival percentage

Cuttings grown with an IBA concentration of 5000 ppm recorded the highest percentage survival with an average of 81.85%. The survival of cuttings grown using an IBA maximum concentration (7500 ppm) was not significantly different ($P>0.001$) from the number of cuttings grown in the control treatment and the least concentration (2500 ppm) (Figure 3).

Effects of rooting media on survival percentage and number of shoots

Media had significant effects ($P < 0.001$) on survival

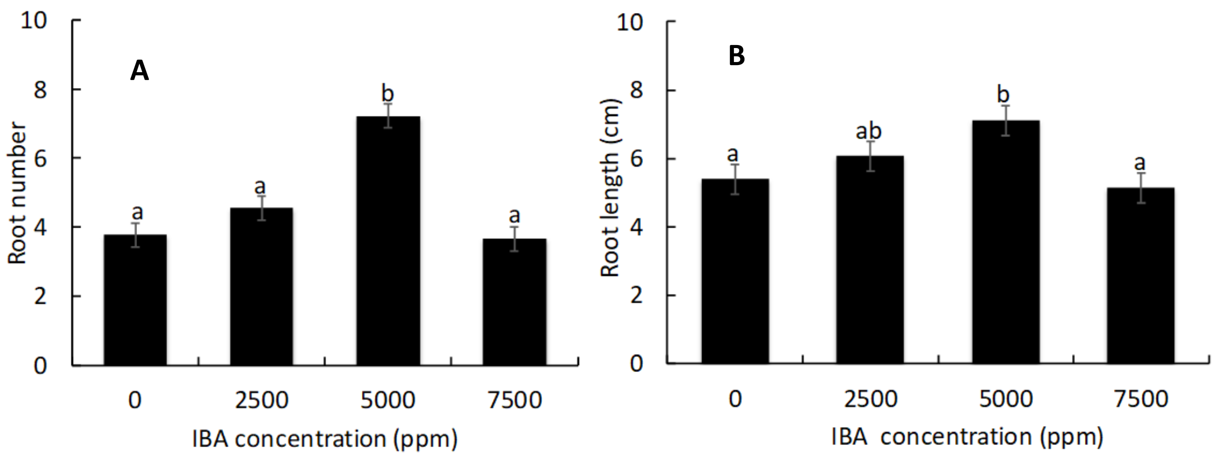

Figure 1. Effects of IBA concentration on root number (A) and root length (B).

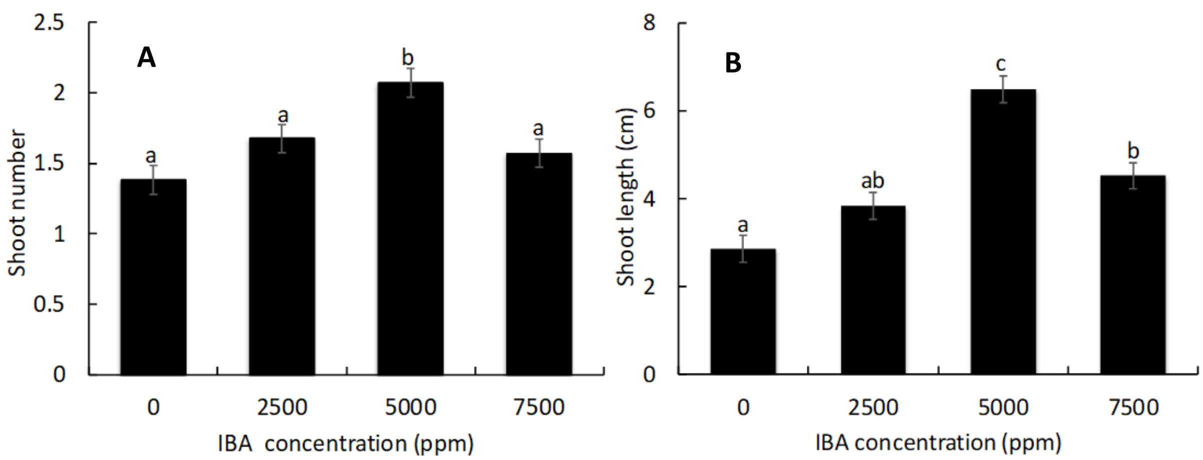

Figure 2. Effects of IBA concentration on shoot number (A) and shoot length (B) of *D. erecta* cuttings.

percentage and number of shoots. Significant variations were obtained on survival of the cutting, with pinebark grown cuttings having the highest survival (Figure 4A). Pinebark grown cuttings had the highest number of shoots, followed by river sand, which was not different from peat-lite (Figure 4B).

DISCUSSION

Effects of IBA concentration on root length and root numbers

The number and length of roots depends on IBA concentration applied during propagation (Figure 1A and B). The results trend on root length can be explained by the fact that proteins from IBA break hydrogen bonds between cellulose micro fibrils promoting cell wall loosening and cells will eventually elongate (Kumar et al., 2015; Qu Yang et al., 2015; Cosgrove, 2000). At optimal exogenous IBA, the rate of cambium de-differentiation is increased, accelerated hydrolytic activity and enhanced callus formation which ultimately gives better root length (Li et al., 2009; Gilani et al., 2019). However, in most species the benefit of exogenous hormones is only realised when they are properly applied, that is the right concentration.

Reduced root length at 7500 ppm can be alluded to the fact that excess IBA can be toxic to the cuttings and reduce callus formation. The current findings are similar to those reported by Sharma et al. (2009) in *Punica garanatum* and Kurd et al. (2010) in olive cuttings; they observed the highest rooting length response at 5000 ppm and a reduced root length at 7500 ppm. Additionally, the trend that comparatively low IBA treatments (2500 ppm) give the least rooting length has been recorded by

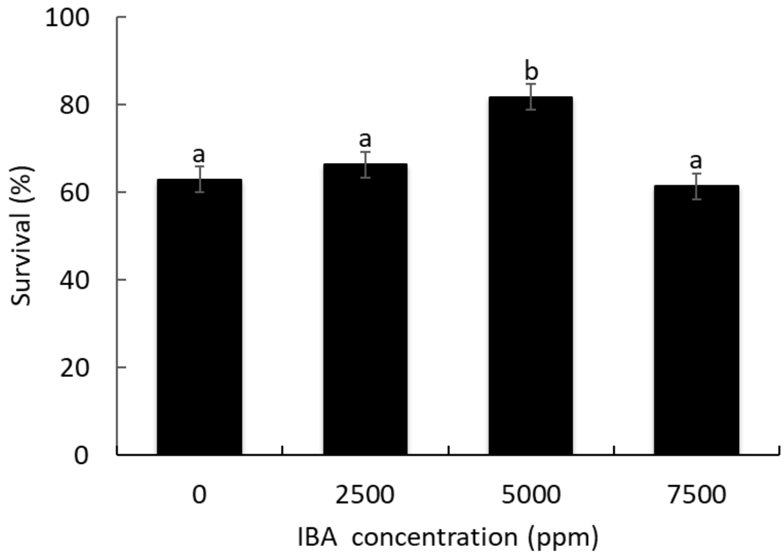

Figure 3. Survival percentage of cuttings from different IBA concentrations.

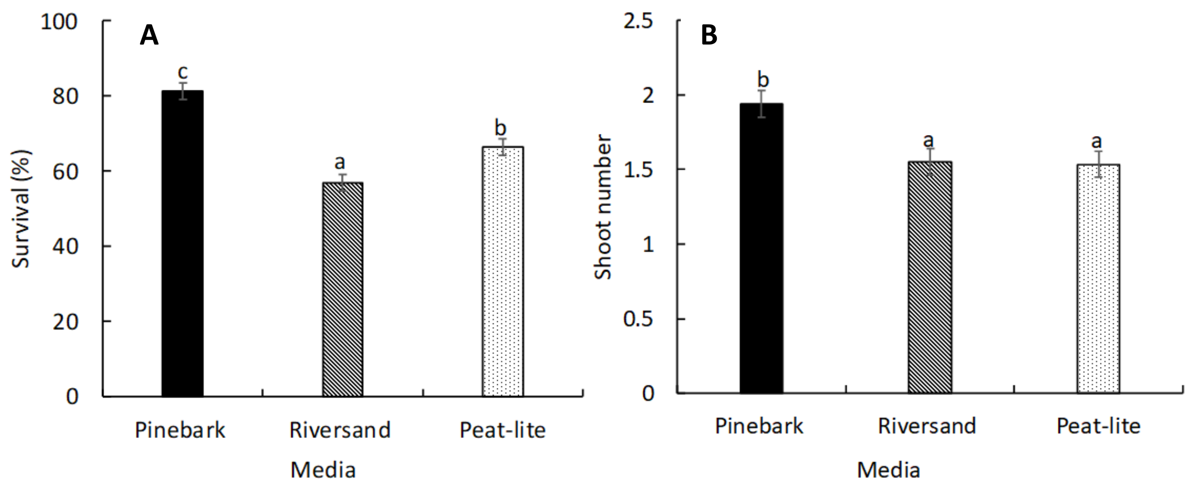

Figure 4. Effects of media on survival (A) and shoot number (B).

many authors like Singh et al. (2014) on *D. erecta* golden stem cuttings Kurd et al. (2010) on Olive stem cuttings, Qaddoury and Amssa (2004) on date palm offshoots.

The highest root numbers at 5000 ppm are in line with the findings of Singh et al. (2014). Singh et al. (2014) explained the higher number of roots at optimum IBA concentration to be a result of less time required to callus formation, thus enhanced cambium dedifferentiation producing numerous cells which will differentiate to form root cells. Optimum IBA increases the rate of amyloplast disappearance, amylolast levels decline naturally during rooting (Singh et al., 2014). Thus our findings indicate that at optimum indole-3-butyric acid, the decline of amylolast can be enhanced and cambium activities are stimulated, that will mobilize stored food material to the root initiation sites (Gilani et al., 2019) hence promoting numerous root formation. This trend is in line with the findings of Mohamed (2005) on *Vitis vinifera* who reported that a concentration of 5000 ppm gives the highest root numbers compared with the highest concentration of 6000 ppm used on medium cuttings.

Effects of IBA concentration on number and length of shoots

Significant variations were observed across various IBA concentrations in terms of shoot number. The high shoot numbers of *D. erecta* cuttings treated with 5000 ppm IBA concentration agree with the findings of Bashir (2009) on *Simmondsia chinensis* stem cuttings. However, auxins being root promoting growth regulators, had no direct impact on shooting of buds as bud shooting is usually influenced by stored carbohydrate in the cuttings. In fact, maximum number of shoots produced from 5000 ppm IBA concentration can be explained by the fact that the same concentration supported better root quality (length and numbers), this increased surface area for nutrient absorption from below ground parts to the above ground parts (Leakey et al., 1990; Gilani et al., 2019).

This trend of results on shoot length can be explained by the same mechanism that influences shoot numbers that is enhancement of mineral nutrients transport by applied IBA to the growing points of the cutting (Akwatulira et al., 2011). Since the same concentration has supported more number of shoots, basically an increase in the number of shoots means more surface area for photosynthesis. More assimilates can translate to an increase in metabolic processes responsible for shoot proliferation (Gilani et al., 2019). However, the mechanism of IBA in promoting shoot growth is not yet clearly understood.

Effects of IBA on survival of cuttings

The results indicate that there is an optimum concentration for IBA beyond which IBA application becomes inhibitory. This was also reported by Anyasi (2011) where maximum IBA concentration resulted in rooting failure of *Chromolaena odorata*. The quantity of IBA applied should be sufficient enough to dissolve the cuticle and provide a tight seal at the basal end of the cutting soon after callusing thus preventing it from decay thus increasing chances of survival. The inhibitory effect by maximum IBA concentration can be explained by the toxicity of potassium (K+) ions which are free radicals. The K+ ions in auxins play a significant role in root initiation by dissolving the epidermal layer. However, when provided in excess instead of dissolving the epidermal layer they actually destroy the epidermal layer and adjacent cells. These findings go in line with the findings of Sharma et al. (2009) who observed that a concentration of 5000 ppm IBA has the highest survival percentage (100%) of *P. garanatum* cuttings whilst 10000 ppm gives the least survival percentage of cuttings.

Rooting media on survival of cuttings and shoot number

The results showed a trend at which pine bark grown cuttings had the highest survival and shoot length. Accelerated survival supported by pine bark can be explained by its low pH range (3-6) (Hartmann et al., 2002). The hydromorphic characteristics of *D. erecta* possibly require acidic conditions to be fully expressed. Also it can be due to the high water holding capacity of pine bark, given the physical properties of pine bark compared to river sand and peat-lite which are loose in texture (Akwatulira et al., 2011). Aeration and water holding capacity of the media are often negatively correlated and therefore a balance between these must be achieved to ensure optimal rooting (Ofori et al., 1996; Kumar et al., 2015). However, the trade-off varies with species, the present findings suggest that *D. eracta* does better in media with a higher water holding capacity compared to better aeration status. High survival of cuttings when rooted in pine bark agrees to the findings of Akwatulira et al. (2011) who observed and recorded a higher survival percentage in pine bark compared with sand and top soil in the rooting *Warburgia ugandensis* stem cuttings. A similar trend was observed in *Prunus africana* where sand grown cuttings had the intermediate survival percentage compared to other media mixtures (Tchoundjeu et al., 2002). Anyasi (2011) also found that sand and a mixture of peat and perlite give the least survival percentage on *C. odorata*.

Pine bark grown cuttings had the highest shoots number, river sand and peat-lite gave almost equal shoot number. These findings are in consistency with the findings of Akwatulira et al. (2011) who observed the maximum number of shoots in *W. ugandensis* grown in pine bark. Given the better water holding capacity of pinebark, we can suggest that pinebark enhances the availability of water and mineral nutrients at the basal end of the cuttings. This makes translocation of water and mineral nutrients to the above ground parts of the cuttings leading to rapid bud break (Akwatulira et al., 2011; Gilani et al., 2019).

Conclusion

The results showed that *D. erecta* propagation is media and IBA concentration dependant. Even though there are various levels of IBA which can used to propagate *D. erecta* cuttings, a concentration of 5000 ppm IBA is the most appropriate concentration in improving survival of cuttings, root number and length, shoot length and shoot numbers. Based on these findings, it can be concluded that 5000 ppm IBA is the optimum concentration for propagating *D. erecta*. Results from the current study also showed that pine bark is an appropriate rooting media as it increases the survival of cuttings and shoot numbers. The study has shown that root length, root number and shoot length are independent of media used. The influence of time of the year when the cuttings are prepared and the effect of cutting length need to be assessed since these have a bearing on the amount of stored carbohydrates which affect the rooting performance of cuttings. Nursery growers are recommended to use a concentration of 5000 ppm IBA and pine bark as the rooting media to maximise production of *D. erecta* cuttings.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Effects and economically feasible rates of nitrogen and phosphorus fertilizers on potato (*Solanum tuberosum* L.) production for rainy season

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Potato is very important food and cash crop in Ethiopia. However, a factor like poor soil fertility is a critical challenge of its productivity. Nitrogen (N) and phosphorus (P) are first and second essential macro-elements and are limiting nutrient in potato production. Therefore, a field experiment was conducted to assess response of N and P fertilizers and select economically feasible fertilizer rate for a rainy season. Four levels of N (0, 55, 110, 165 kgha^{-1}) and 4 levels of P (0, 45, 90, 135 kgha^{-1}) were combined in 4×4 factorial arrangement in randomized complete block design with 3 replications. Raising the application of NP fertilizer levels to 165 and 135 kgha^{-1} delayed days to flowering (9.48 and 4.46 days), while maturity extends 14 and 10.18 at Dabark and Dabat, respectively. Application of 110 to 90 and 165 to 45 kgha^{-1} NP increased marketable tuber number by 122 and 119%, respectively. Similarly, 165 to 90 and 165 to 45 kgha^{-1} NP raised marketable tuber yield by 141.8 and 127.5%. However, both 165 to 90 and 165 to 45 kgha^{-1} NP had MRR below acceptable level (<100%). In contrary, application of 110 to 90 kg ha^{-1} NP resulted in 136.6 and 125.4% marketable tuber yield increment and MRR of 1993.72% for Dabark and 1376.5% for Dabat location. Therefore, application of 110 to 90 kgha^{-1} NP was proven to have high MRR and can be used for the studied areas.

Key words: Marginal rate of return, *Solanum tuberosum*, marketable tuber yield, interaction effect, main effect.

INTRODUCTION

There have been several scientific advances in the field of agriculture and food security, yet there are still several challenges in many countries mainly sub-Saharan Africa developing countries including Ethiopia are not able to be food secured. The demand of food is likely to rise significantly as a result of population growth. To meet the ever increasing demand for food, roots and tuber crops including potato can play a major role in addressing this issue and feed millions of people. Especially, in Ethiopia root and tuber crops are part of the traditional food systems of the people. Hence, there is enormous possibility for millions of poor farmers to boost production and their livelihood using root and tuber crops which are strategic crops for the country's economy (Amsalu et al., 2008).

Potato (*Solanum tuberosum* L.) is the fourth most

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Table 1. Pre planting soil laboratory analysis result.

Parameter	Value at Dabat	Value at Dabark
pH	5.65	5.91
Total nitrogen (%)	0.239	0.192
Available phosphorus (ppm)	10.65	26.91
Organic matter (%)	5.57	4.47
EC (mS/cm)	0.14	0.17
Cation Exchange Capacity ($Cmol_c$ /kg)	43.87	40.44

important crop and consumed all around the world and is one of the main favorite vegetable in Ethiopia. It is a very important food and cash crop in the country especially when the grains get depleted from the store. It is a very nutritious food which requires less land, grows quickly and easily even in harsh conditions. It has double cropping advantages and its utilization in different forms (Muthoni and Nyamongo, 2009). Ethiopia has favorable agro ecology and wide production area for potato. However, the national productivity is still very low (CSA, 2016) as compared to the potential of the crop. There are various factors that contribute to the low yields of potatoes. Poor soil fertility is one of the principal factors hampering potato production in Ethiopia (Gebremedhin et al., 2008; Adane et al., 2010).

It is obvious that growth, yield and quality of potato are greatly affected by its nutritional management. The potato has a shallow rooting system to exploit fully the nutrients and it is also heavy feeder. Among the nutrients, N and p are the first and the second essential macro elements and are the limiting nutrient in potato production thus has a great influence on crop growth, tuber yield and its quality (Trehan et al., 2008). N is a constituent of numerous organic molecules in plant such as proteins, nucleic acids and alkaloids, enzymes, chlorophyll-a, chlorophyll-b, etc. (Pushpalatha et al., 2017). Hence, a mature crop of potato yielding 25 to 30 t/ha tubers removes 120 to 140 kg N/ha. Also for potato production, phosphorus is another limiting nutrient and a healthy crop of potato removes about 25 to 30 kg P_2O_5 (Trehan et al., 2008). Moreover, P and N are susceptible to loses, principally through immobilization, volatilization, leaching and runoff under poor agronomic management (Hopkins et al., 2014; Rens et al., 2018). Hence, application of N and P fertilizers becomes indispensable to meet the needs of the crop.

To apply those macro nutrients there should be clear and economical feasible recommendation. However, there was no such recommendation around Dabat and Dabark districts of North Gondar Administrative Zone which is very potential for potato production. There was national blanker fertilizer recommendation but the soil and the agroecologist vary from area to area moreover the recommendation was done before a decade. Therefore, the present study was conducted to assess the response of potato to different rates of N and P fertilizers and to select economically feasible combination of fertilizer rate for rainy season potatoes production of the study areas.

MATERIALS AND METHODS

This study was conducted at Dabat and Dabark district of North Gondar Administrative Zone during 2016 to 2018 main cropping seasons. Belete (CIP-393371.58) potato variety obtained from Holeta Agricultural Research Center was used for this experiment. It is one of the potential potato cultivars for both districts in North Gondar zone of Ethiopia and it is the most NP efficient variety than others in all efficiency indices (Hailu et al., 2017; Solomon et al., 2019). Four levels of nitrogen: 0, 55, 110 and 165 kg and four levels of phosphorus: 0, 45, 90 and 135 kg/ha were combined in 4×4 factorial arrangements in randomized complete block design with three replications. All management practices were applied as per the general recommendations for potato (Gebremedhin et al., 2008).

The study area has a clay loom soil which was plowed 3 times using oxen. Prior to planting, representative soil samples were taken using an auger from the top 0 to 30 cm and combined into a composite sample. Working samples were analyzed in the laboratory using the standard procedure for each of the soil pH, organic carbon, total N, available phosphorus, and cation exchange capacity (CEC). The experimental field was divided into three blocks each containing 16 plots and a plot size of 9 m^2. Sprouted tubers in the diffused light store (DLS) were planted by hand in rows 75 cm apart and with 30 cm between plants within rows (Zelalem et al., 2009; Israel et al., 2012). Blocks were separated by 1.5 m. There were 4 rows/plot for each treatment. Data were collected from the middle 2 rows; the outermost rows and terminal plants were borders. The entire rate of phosphorus and half the rate of nitrogen was applied at the time of planting and the remaining half of nitrogen was applied 45 days after planting. Urea (46%N) and triple super phosphate, TSP (46% P_20_5) fertilizers were used as sources of N and P. Earthening up and weeding were each carried out 3 times by hand during the growing period (Table 1).

Data collection and analysis

Data collected on growth parameters such as days to 50% flowering and maturity, plant heights, number of stem per plant and yield parameters such as total tuber number, marketable and unmarketable tuber number, marketable, unmarketable and total tuber yields (t ha^{-1}) were checked for constant variance and normality and subjected to analysis of variance using SAS version 9.2 statistical software (SAS, 2008). Treatment means were compared using LSD value at 5% significant level.

Table 2. Days to flowering, maturity, plant height and number of stem as affected by the main effect (combined over year).

Treatment	Dabark (2016-2018)				Dabat (2016-2018)			
Nitrogen (kg ha^{-1})	**DTF**	**DTM**	**PHT**	**NST**	**DTF**	**DTM**	**PHT**	**NST**
0	60.37^b	115.02^c	56.07^c	4.49^b	60.06^c	118.8^c	51.62^c	3.86^c
55	61.39^b	120.66^b	59.32^b	5.65^a	62.9^b	122.15^b	58.85^b	4.19^c
110	63.08^a	122.97^a	64.4^a	5.5^a	62.38^b	123.2^b	64.67^a	5.12^a
165	63.6^a	125.2^a	63.4^a	5.88^a	64.15^a	125.16^a	64.1^a	4.7^b
Significance level	**	**	**	**	**	**	**	**
P_2O_5 (kg ha^{-1})								
0	59.56^c	119.64	55.29^c	5.14	61.05^c	120.32^b	54.27^c	4.06^b
45	62.35^b	120.04	62.62^{ab}	5.74	62.05^b	121.44^b	57.74^b	4.41^b
90	62.52^b	121.81	63.58^a	5.26	63.5^a	123.67^a	62.52^a	4.95^a
135	64.02^a	122.37	61.69^b	5.42	62.89^{ab}	123.89^a	64.73^a	4.45^b
Significance level	**	ns	**	Ns	**	**	**	**
CV (%)	3.2	5.37	5.11	21.71	1.88	2.25	9.82	15.76
LSD (5%)	1.14	3.74	1.79	0.67	0.67	1.59	3.39	0.4
Mean	62.11	120.9	60.8	5.39	62.37	122.33	59.81	4.47

DTF=Days to flowering, DEM=days to maturity, PHT=plant height (cm), NST=number of stem per plant, [ns]Non-significant, **Highly significant (p<0.01).

Partial budget analysis was employed for economic analysis of fertilizer application using a technique described by CIMMYT (1988). The marketable tuber yield data was adjusted by bringing down 10% to minimize plot management effect by the research or to reflect the actual farm level performance. To estimate the total costs, mean market prices of urea and DAP, cost of fertilizer transportation and labor for application of fertilizer were taken from market assessment at the time of planting and market price of potato tubers was taken after harvest.

RESULTS AND DISCUSSION

Days to 50% flowering and maturity

At Dabark site, the main effect of N and P was significantly influenced by the number of days to flowering and maturity than their interaction. As the level of nitrogen rose from 0 to 165 kg ha^{-1}, days to 50% flowering was late by 3 days (Table 2). Likewise, as the rate phosphorous increased from 0 to 135 kg ha^{-1} the days to 50% flowering was delayed by 4 day as compared to untreated potato plant. Only the main effect of nitrogen fertilizer rate showed a significant effect on the days to maturity and as the level of nitrogen increased from 0 to 165 kg ha^{-1} maturity was delayed by 10 days.

At Dabat, the main effects of nitrogen and phosphorus as well as their interaction effect were significantly influenced both days to flowering and days to maturity. The main effects revealed that as the level of N increased days to flowering and maturity extended. Similarly, as the rate of P increased up to 90 kg ha^{-1} the number of days to both traits increased but increasing the rate above this level did not create significant difference. On the other hand, the interaction effect revealed that an application of 165 kg ha^{-1} nitrogen with 135 kg ha^{-1} phosphorous delayed the number of days to flowering by about 20% followed by 165 kg ha^{-1} with 90 kg ha^{-1} phosphorous which delayed 13.2% as compared to unfertilized plant (Table 3). Similarly, days to maturity was prolonged by 9 days when 165 kg ha^{-1} nitrogen with 90 and 45 kg ha^{-1} phosphorous fertilizer were applied as compared to unfertilized plant.

This may be due to the application of nitrogen fertilizer which may result to a chance to increase the nitrogen uptake and this increase has a positive effect on chlorophyll concentration, encourage the vegetative growth, increased the amount of solar radiation intercepted, prolonged the canopy life of the plant, enabled the potato plant to maintain physiological activity for an extended period, thereby continuing photosynthesis. Therefore, a plant which received more nitrogen will mature later in the season than a crop that received less N because later growth is related to excessive haulm development while early tuber growth to less abundant haulm growth (Mulubrhan, 2004; Najm et al., 2010). On the other hand, application of higher rate of phosphorus may enhance the development of roots particularly lateral and fibrous rootlets which may support the active above ground vegetative growth in provision of water and like.

The observations of the current investigation was in

Table 3. The interaction effects of nitrogen and phosphorous on days to 50% flowering and days to maturity (Dabat site).

P_2O_5 (kg ha^{-1})	Days to 50% flowering				Days to maturity			
	Nitrogen (kg ha^{-1})				Nitrogen (kg ha^{-1})			
	0	55	110	165	0	55	110	165
0	56.48^{f}	62.38^{cd}	61.93^{d}	63.36^{bc}	117.13^{fg}	118.96^{ef}	121.03^{cde}	124.15^{abc}
45	59.33^{e}	62.83^{bcd}	62.73^{bcd}	63.3^{bcd}	120.86^{de}	122.98^{bcd}	124.53^{ab}	126.33^{a}
90	62^{d}	62.73^{bcd}	62.86^{bcd}	63.96^{b}	122.03^{bcde}	122.23^{bcd}	125.11^{ab}	126.18^{a}
135	62.43^{cd}	63.65^{bc}	61.95^{d}	65.96^{a}	112.26^{g}	124.41^{ab}	122.11^{bcde}	123.98^{abcd}

LSD=1.35 and 3.18, for days to 50% flowering and days to maturity, respectively.

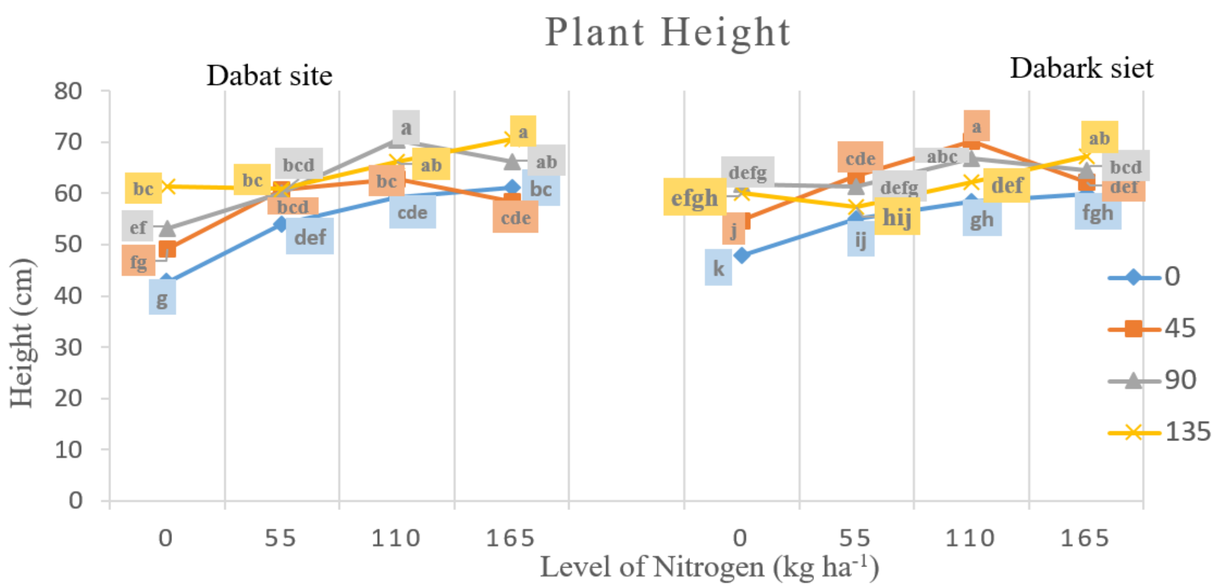

Figure 1. The interaction effect of N and P on plant height at Dabat and Dabark, LSD = 6.78 and 3.59, respectively.

conformity with the previous findings of Zelalem et al. (2009) who reported a significant 4 and 9 days delayed flowering and maturity due to increase of the rate of 0 to 207 kg N/ha, respectively. The same author also mentioned, increasing phosphorous application from 0 to 60 kg/ha prolonged the days to flowering by about 2 days. The study partially agrees with Firew et al. (2016) who reported that the main effect of nitrogen and phosphorous had significant effects on days to maturity rather than their interaction and the increased application rate of nitrogen delayed days to maturity up to 32% but increased application of phosphorus reduced days to maturity. On the other hand, Niguse (2016) reported that the application of phosphorous fertilizer significantly influenced days to flowering and maturity where the application at the rate of 89.7 kg ha^{-1} is delayed by 3 and 7 days, respectively. Also Girma et al. (2017) reported the significant effect of nitrogen on days to flowering and maturity which delayed 7 and 12 days, respectively due to increasing of the rate of 0 to 138 kg N ha^{-1}.

Plant height

The current study revealed that nitrogen, phosphorus and their interaction significantly influenced the height of potato at both locations. The main effects of nitrogen at Dabark and Dabat showed that as the rate increased 0 to 110 kg ha^{-1} plant height increased by 8 and 13 cm at respective locations but there was no apparent significant increment above this rate (Table 2). Similarly, phosphorous increased the height by 15% at Dabark and 19% at Dabat as the level increased from 0 to 90 and 135 kg ha^{-1}, respectively. On the other hand, the interaction effect of both nutrients showed that the height of the plant increased as the level of nitrogen increased along with phosphorous (Figure 1). The maximum plant height (70.63 cm) at Dabat site was recorded from the application of 165 kg ha^{-1} nitrogen with 135 kg ha^{-1} phosphorous as closely followed by 110 kg ha^{-1} nitrogen with 90 kg ha^{-1}. These rates resulted in 65.2 and 64.9% height difference, respectively as compared to untreated

Table 4. Marketable and total number of tuber, marketable and total yield of potato as affected by the main effect (N and P).

Treatment	Dabat (2016-2018)				Dabark (2016-2018)			
Nitrogen (kg ha^{-1})	**NMT**	**TTN**	**YMT**	**TTY**	**NMT**	**TTN**	**YMT**	**TTY**
0	4.69^{c}	13.05^{a}	17.47^{c}	22.78^{b}	5^{c}	13.6^{ab}	17.86^{b}	23.09^{b}
55	5.55^{b}	13.47^{a}	19.48^{b}	24.4^{b}	6.01^{b}	14.08^{a}	18.87^{b}	23^{b}
110	6.87^{a}	11.9^{b}	24.03^{a}	28.92^{a}	7.15^{a}	12.44^{b}	24.05^{a}	27.81^{a}
165	6.81^{a}	11.77^{b}	23.99^{a}	28.99^{a}	7.16^{a}	13.33^{ab}	24.37^{a}	28.75^{a}
Significance level	**	**	**	**	**	*	**	**
Phosphorus (kg ha^{-1})								
0	5.7b^{c}	14.02^{a}	18.25^{c}	24.23^{c}	5.81^{b}	15.19^{a}	17.82^{c}	23.31^{c}
45	5.19^{c}	13.23^{a}	19.2^{c}	24.61^{c}	6.01^{b}	13.63^{b}	21.58^{b}	25.71^{b}
90	7.27^{a}	11.51^{b}	22.28^{b}	19.55^{a}	6.9^{a}	12.94^{b}	22.8^{ab}	27.14^{a}
135	5.77^{b}	11.42^{b}	25.24^{a}	26.7^{b}	6.59^{a}	11.9^{b}	22.95^{a}	26.49^{ab}
Significance level	**	**	**	**	**	**	**	**
CV (%)	15.94	11.19	13.81	11.1	14.91	15.03	10.89	8.9
LSD (5%)	0.55	0.81	1.69	1.68	0.54	1.15	1.33	1.31
Mean	5.98	12.55	21.24	26.27	6.33	13.36	21.29	25.66

NMT=Number of marketable tuber, TTN=total tuber number, YMT=yield of marketable tuber, TTY=total tuber yield, ^{ns}nonsignificant, *Significant at 5%, **Significant at 1%.

plant. While at Dabark, the maximum plant height (70.16 cm) was recorded from the application of 110 kg ha^{-1} nitrogen along with 45 kg ha^{-1} which resulted to 46.7% height increment.

This might be due to the obvious positive effect of nitrogen in enhancing vegetative growth which seemed to be more superior due to the presence of phosphorus that may stimulate the growth and development of roots for efficient water and other important nutrient uptake. In line with this idea Brady and Weil (2002) reported that phosphorous is required in large quantities in young cells, like root and shoot tips, where high metabolism, cell division and development is rapid.

The current finding is in agreement with Firew et al. (2016) who had reported significant effect of nitrogen, phosphorus and their interaction that resulted in 79.3 cm height difference due to the combined application of 168 kg N ha^{-1} with 138 P_2O_5 kg ha^{-1} as compared to untreated/plot. Similarly, Zelalem et al. (2009) reported 24 and 10.5 cm height difference due to the application of 207 kg N/ha and 60 kg P/ha, respectively as compared to the untreated. Also, Israel et al. (2012) found that increasing application of nitrogen and phosphorus significantly increased plant height.

Stem numbers

The main effect of nitrogen affected the number of main stems per plant rather than phosphorous or their interaction at Dabark. The unfertilized potato had lesser number of stems and significantly differed from fertilized plants. However, there was no significant difference among fertilized plants. On the other hand, at Dabat the main effect of both N and P significantly influenced the number of stems but not their interaction (Table 2). Application at lower rate mean that nitrogen up to 55 kg ha^{-1} or phosphorous up to 45 kg ha^{-1} did not create a significant effect on the number of stems but raising the rate to 110 and 90 kg ha^{-1}, respectively had significant influence on stem numbers. The maximum number of stem (5.88 and 5.12) was recorded from application of 165 and 110 kg ha^{-1} N at Dabark and Dabat, respectively. The current finding is in agreement with Jamaati-e-Somarin et al. (2009) who confirmed the effect of N on the number of stems and they stated that an application of N levels up to 110 kg/ha N_2 increased the number of stems; but further increases in N above this level did not affect the numbers of the stem.

Number of marketable tubers

The number of marketable per plant was significantly influenced by the fertilizer rate of nitrogen and phosphorous as well as their interaction. In the present study, as a main effect raising the rate of N up to 110 kg ha^{-1} increased the number of marketable tubers but did not have significant effect after this rate at both locations whereas raising the level of phosphorous up to 135 kg ha^{-1} provided the maximum number of marketable tubers at both locations (Table 4). The interaction effect of

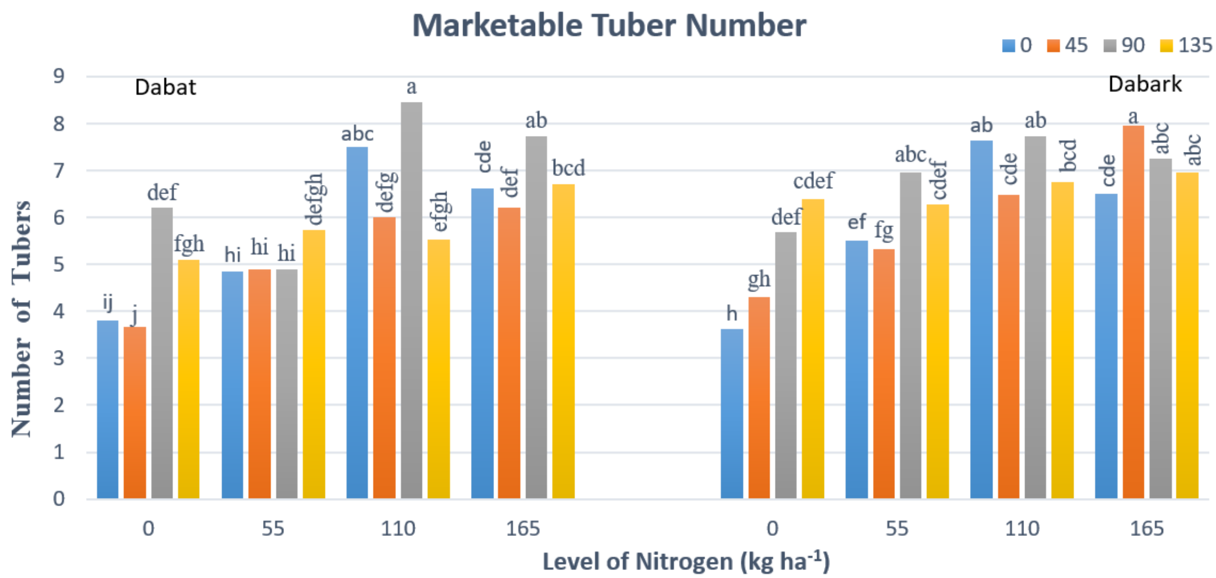

Figure 2. The interaction effect of nitrogen and phosphorous on marketable tuber yield at Dabat and Dabark (LSD =1.1 and 1.09 respectively).

nitrogen and phosphorous at Dabat site showed that the number of marketable tubers were increased by 122% as the rate raised up from 0 to 110 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous (Figure 2).

At Dabark site, the maximum number of marketable tubers (7.95) were recorded from the application of 165 kg ha^{-1} nitrogen along with 45 kg ha^{-1} phosphorous closely followed by 110 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous which were not statistically different. These rates resulted in 119 and 113% increment of marketable tuber number as compared to unfertilized plants.

This may be due to decrease in the number of the small size tubers and increased weight of individual tubers because of accumulation of more photo assimilate in the tuber that resulted from more vegetative growth and good root performance. It may also be linked to solar radiation intercepted and more photos assimilate production initiated from application of nitrogen and phosphorous. In this connection, Trehan et al. *(*2008) reported that the potato plants with sufficient nitrogen were characterized by vigorous growth, increased leaf area index and large tuber size as well as numbers.

The result of the current study is in conformity with Israel et al. (2012) who reported 20.49 to 56.36% marketable number of tuber increment was due to the application of N and P. Similarly, Firew et al. (2016) reported a significant influence of N and P on the number of marketable tuber and raising the rate of N from 0 to 56 kg ha^{-1} resulted in 8.4% increment while increasing phosphorus rate from 0 to 138 Kg ha $^{-1}$ increased by 67%. Rens et al. (2018) reported that as the rate of nitrogen fertilizer increase, the number of larger tuber sized potato increased. Also, Niguse (2016) reported that the application of phosphorous fertilizer affects the number of tuber per plant.

Total tuber number

The rate and type of fertilizer significantly influenced the number of total tuber per plant. The main effect of nitrogen and phosphorous level revealed that above 55 kg N ha^{-1} and 45 kg P_2O_5 ha^{-1}, respectively decreased the number of total tuber significantly at both locations (Table 4). Similarly, the interaction effects of the two nutrients showed that the total number of tubers was decreased as the combined level of nitrogen and phosphorous increased as compared to untreated and lesser fertilizer rate (Figure 3). For both location, the maximum number of total tuber was found from untreated plant and the minimum of total tuber number were from the application of 135 kg ha^{-1} phosphorous with 0 nitrogen. Here, as the rate of fertilizer increase, the number of marketable tuber increases but the number of total tuber decreases. It was clear that untreated plants gave 17.31 total number of tuber from which 3.81 were marketable tuber at Dabat, whereas 110 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous gave 12.31 total number of tubers from which 8.46 were marketable tuber.

Similarly, at Dabark, 165 kg ha^{-1} nitrogen with 135 kg ha^{-1} phosphorous gave 6.95 marketable tubers among a total of 12.48 tubers while the untreated gave 17.21 total tubers among which 3.63 were marketable. Probably, this might be due to less nutrient availability that causes lesser vegetative growth, lesser photo assimilate and less starch to be stored that resulted in smaller tubers. This

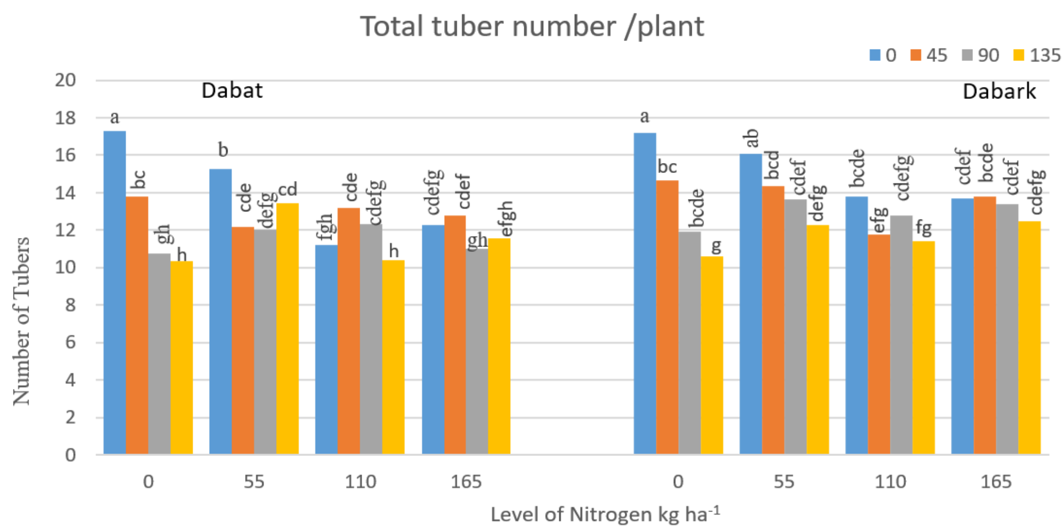

Figure 3. The interaction effect of nitrogen and phosphorous on total tuber number at Dabat and Dabark (LSD= 1.62 and 2.31, respectively).

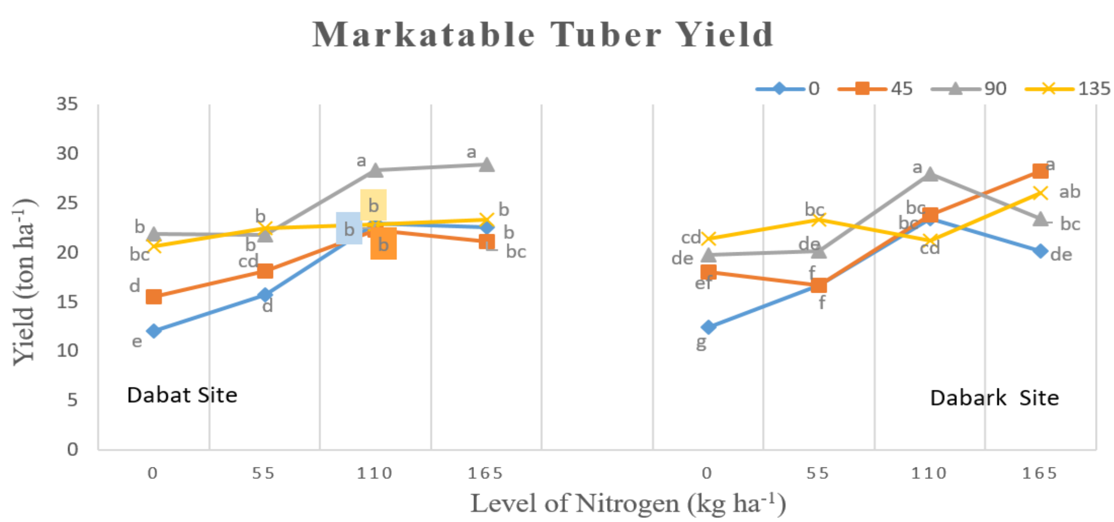

Figure 4. The interaction effect of nitrogen and phosphorous on marketable tuber yield at Dabat and Dabark, LSD = 3.38 and 2.67, respectively.

result is in line with the finding of Mutubuki et al. (2015) who reported that as the rate of nitrogen increase, the total number of tubers was decreased significantly. Also, Firew et al. (2016) reported a significant influence of the interaction of nitrogen and phosphorous that revealed 25.9% decline in total number of total tubers as the rate of fertilizer increased from 0 to 168 kg N ha^{-1} with 138 kg ha^{-1} P_2O_5.

Marketable tuber yield

Nitrogen, phosphorous and their interaction affected marketable tuber yield of potato significantly. The result showed that increasing the rate of nitrogen and phosphorous increased the marketable tuber yield. At Dabat, an application of 0 to 165 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous results in 141.8% marketable tuber yield increment, closely followed by 110 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous that resulted in 136.6% increment (Figure 4). However, the application of 165 kg ha^{-1} nitrogen with 135 kg ha^{-1} phosphorous resulted in 24.6% lesser yield as compared to the 165 kg ha^{-1} nitrogen and 90 kg ha^{-1} phosphorous.

At Dabark, the maximum marketable tuber yield was recorded from the application of 165 kg ha^{-1} nitrogen with 45 kg ha^{-1} phosphorous followed by 110 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous. Each of these fertilizer combinations resulted in 127.5 and 125.4% increment of marketable tuber yield as compared to untreated plant.

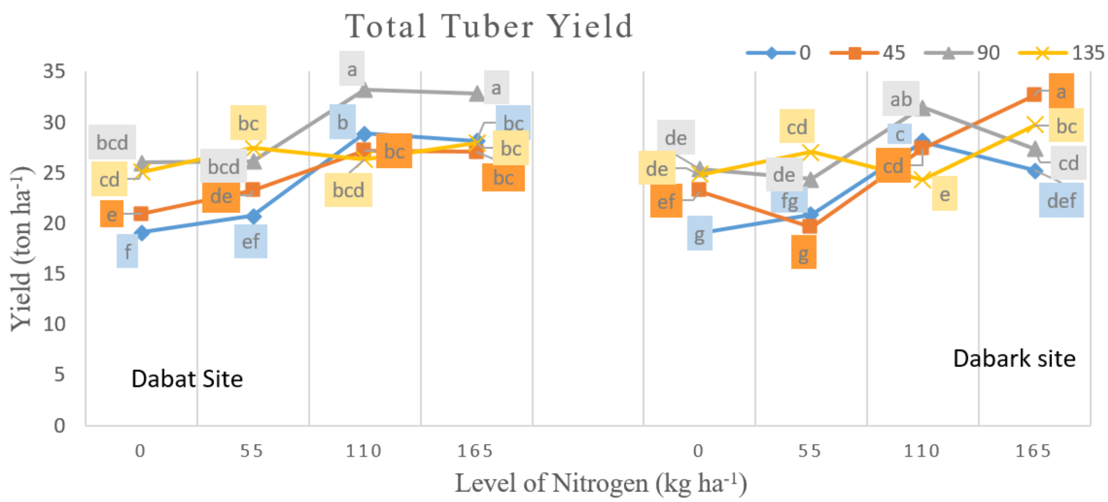

Figure 5. The interaction effect of nitrogen and phosphorous on total tuber yield at Dabat and Dabark, LSD= 3.36 and 2.63, respectively.

Both of these rates were not statistically significant to each other. But the application of 165 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous decreased the marketable tuber yield by 20.05% as compared to 165 kg ha^{-1} nitrogen with 45 kg ha^{-1} phosphorous application.

This may be associated with vigorous vegetative growth and the positive interaction and complementary effect between nitrogen and phosphorus in affecting and increasing the marketable tuber yield of potato in the study areas. This is supported by FAO (2000) that reported without phosphorus application, nitrogen efficiency declined thereby indicating interaction between these nutrients.

This result is in agreement with the findings of Desalegn et al. (2016) who had reported a significant interaction effect of nitrogen and phosphorous which resulted in 4 times marketable tuber yield increment as the rate increase from 0 to 140 kg ha^{-1} nitrogen and 90 kg ha^{-1} phosphorous. Similarly, Qadri et al. (2015) and Hailu et al. (2017) reported that as the rate of nitrogen and phosphorous application had increased the marketable tuber yield was increased significantly. Niguse (2016) reported that the application P significantly affects the marketable tuber yield and resulted in 20% increment as the rate increased from 0 to 89.7 kg/ha while the total tuber yield increased by 19.2%.

Total tuber yield

Total tuber yield was significantly affected by the main and interaction effect of N and P fertilizers. As the main effect reveals increasing level of nitrogen up to 55 kg/ha, did not significantly affect it in both locations (Table 4). Likewise, increasing the rate of phosphorous up to 45 kg/ha did not have significant effect at Dabat but not at Dabark. However, raising the level of both nutrients above these rates affected total tuber yield significantly. On the other hand, the interaction effect revealed the maximum total tuber yield (33.2 t/ha) was found from the application of 110 kg ha^{-1} nitrogen along with 90 kg ha^{-1} phosphorous at Dabat while the maximum total yield (32.66 t/ha) of Dabark was from the application of 165 kg ha^{-1} nitrogen with 45 kg ha^{-1} phosphorous (Figure 5). Due to the application of 110 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous the total yield increased by 73.8% at Dabat followed by 71.7% from the application of 165 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous. Similarly, at Dabark, 71.4% yield increment was recorded from the application of 165 kg ha^{-1} nitrogen with 45 kg ha^{-1} phosphorous followed by 65.1% increment that resulted from the application of 110 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous.

The decline in yield, as the level of fertilizer increases, indicates the optimum rate of nitrogen and phosphorus for better tuber yield was already attained and it was not agronomically necessary and beneficial to increase the rate of the fertilizer further. The present study trend showed that, as the rate of fertilizer application increased the marketable tuber number and marketable tuber yield increased which raised the total tuber yield. This is in support with Gitari et al. (2018) that found the strong and positive correlation of tuber yield with N and P levels.

The result is in agreement with the previous study of Qadri et al. (2015) who reported that the marketable tuber yield and total tuber yield increased as the amount and accessibility of nitrogen and phosphorous nutrient increased. Also Israel et al. (2012) and Desalegn et al. (2016) reported significant effects of nitrogen and phosphorous fertilizer to increase the total tuber yield of potato. Pushpalatha et al. (2017) reported that nitrogen had a significant effect on potato tuber yield and

Table 5. Partial budget analysis fertilizer rate for the Dabark site combined over the year (2016-2018).

Treatment combination		Marketable yield (kg/ha)	Adjusted yield (kg/ha)	Gross field benefit	Fertilizer cost	Labor for fertilizer application	Fertilizer transport cost	Total variable cost	Net benefit	Marginal net benefit	Marginal variable cost	Marginal Rate of Return (Eth. Birr)
N_2	P_2O_5											
0	0	12400	11160	55800	0	0	0	0	55800	-	-	-
0	45	17960	16164	80820	1150	180	60	1390	79430	23630	1390	1700
55	0	16650	14985	74925	1647	225	140	2012	72913[d]	-	-	-
55	45	16650	14985	74925	2248	300	120	2668	72257[d]	-	-	-
0	90	19750	17775	88875	2300	360	120	2780	86095	6665	1390	479.49
110	0	23350	21015	105075	2745	420	150	3315	101760	15665	535	2928.04
55	90	20080	18072	90360	2849	420	150	3419	86941[d]	-	-	-
110	45	23730	21357	106785	3346	540	180	4066	102719	959	751	127.69
55	135	23300	20970	104850	3470	480	165	4115	100735[d]	-	-	-
0	135	21350	19215	96075	3450	540	180	4170	91905[d]	-	-	-
165	0	20080	18072	90360	3979	660	220	4859	85501[d]	-	-	-
110	90	27950	25155	125775	4093	660	220	4973	120802	18083	907	1993.72
165	45	28220	25398	126990	4670	780	250	5700	121290	488	727	67.12
110	135	21180	19062	95310	4814	780	250	5844	89466[d]	-	-	-
165	90	23410	21069	105345	5413	840	300	6553	98792[d]	-	-	-
165	135	26000	23400	117000	6123	960	330	7413	109587[d]	-	-	-

Price of Urea=1098 birr qt^{-1}, DAP=1150 birr qt^{-1}, field price of potato=500 qt^{-1}, d=dominated.

application of 125 kg/ha nitrogen results 96.3% yield increment.

Partial budget analysis

The partial budget analysis revealed that fertilizer application of N and P gave the highest gross profit, net return and marginal rate of return compared to the unfertilized plot. From the tested and un-dominated nutrient treatments, the highest net profit per hectare 121290 and 123587 Ethiopia birr were recorded from the application of 165 kg ha^{-1} N with 45 kg ha^{-1} P at Dabark and while 165 kg ha^{-1} N with 90 kg ha^{-1} P at Dabat, respectively (Tables 5 and 6). The lowest net benefit of 55800 and 53820 birr were recorded from unfertilized plot at Dabark and Dabat sites, respectively.

On the other hand, the calculations of marginal rate of return (MRR) realized that among undominated treatment combination, the MRR% from the application of 165 kg ha^{-1} nitrogen with 45 kg ha^{-1} phosphorous at Dabark and 55 kg ha^{-1} nitrogen and 165 kg ha^{-1} nitrogen with 90 kg ha^{-1} phosphorous at Dabat were below the minimum acceptable MRR (100%); that is, 67.12, 44.7 and 76.6%, respectively. The maximum MRR for Dabat was 15087.5% found from the application of only 90 kg ha^{-1} phosphorous while for Dabark 2928.04% was found from the application of 110 kg ha^{-1} nitrogen only. The application of 110 to 90 kg ha^{-1} nitrogen and phosphorous combinations gave MRR of 1993.72% for Dabark and 1376.5% for Dabat location. Application beyond this rate did not give MRR greater than 100% because of increased cost. Hence, application of 110 to 90 kg ha^{-1} nitrogen and phosphorous combination had the highest net benefit and acceptable marginal rate of return for both locations.

Conclusion

The present study of two years at two locations results showed that application of nitrogen and phosphorous had a significant effect on potato, these nutrients had positive and significant effect on growth, yield and yield components except

Table 6. Partial budget analysis fertilizer rate for the Dabat site combined over the year (2016-2018).

Treatment combination		Marketable yield (kg/ha)	Adjusted yield (kg/ha)	Gross field benefit	Fertilizer cost	Labor for fertilizer application	Fertilizer transport cost	Total variable cost	Net benefit	Marginal net benefit	Marginal variable cost	Marginal rate of return (Eth. Birr)
N_2	P_2O_5											
0	0	11960	10764	53820	0	0	0	0	53820	-	-	-
0	45	15450	13905	69525	1150	180	60	1390	68135	14315	1390	1029.9
55	0	15650	14085	70425	1647	225	140	2012	68413	278	622	44.7
55	45	18100	16290	81450	2248	300	120	2668	78782	10369	656	1580.6
0	90	21880	19692	98460	2300	360	120	2780	95680	16898	112	15087.5
110	0	22860	20574	102870	2745	420	150	3315	99555	3875	535	724.3
55	90	21730	19557	97785	2849	420	150	3419	94366d	-	-	-
110	45	22180	19962	99810	3346	540	180	4066	95744d	-	-	-
55	135	22460	20214	101070	3470	480	165	4115	96955d	-	-	-
0	135	20580	18522	92610	3450	540	180	4170	88440d	-	-	-
165	0	22550	20295	101475	3979	660	220	4859	96616d	-	-	-
110	90	28300	25470	127350	4093	660	220	4973	122377	22822	1658	1376.5
165	45	21050	18945	94725	4670	780	250	5700	89025d	-	-	-
110	135	22780	20502	102510	4814	780	250	5844	96666d	-	-	-
165	90	28920	26028	130140	5413	840	300	6553	123587	1210	1580	76.6
165	135	23310	20979	104895	6123	960	330	7413	97482d	-	-	-

Price of UREA=1098 birr qt^{-1}, DAP=1150 birr qt^{-1}, field price of potato=500 qt^{-1}, d=dominated.

days to flowering and maturity which were delayed up to 9.48 and 9.2 days, respectively. However, application of high amount of N in line with P like from 110 to 90 and 165 to 45 kg/ha N and P increased the number of marketable tuber by 122 and 119% at Dabat and Dabark, respectively. Similarly, application of 165 to 90 and 165 to 45 kg/ha nitrogen and phosphorous raised the marketable tuber yield by 141.8 and 127.5%. On the other hand, total tuber yield increased by 74.1 and 72.7% from the application of 165 to 90 and 165 to 45 kg/ha nitrogen and phosphorous as compared to unfertilized plots. The effect of N and P was evidenced by partial budget analysis which revealed high marginal rate of returns. Even though, 165 to 45 and 165 to 90 kg ha^{-1} nitrogen and phosphorous were high yielder, their MRR was below the acceptable level. On the contrary, 110 to 90 kg ha^{-1} nitrogen and phosphorous combinations gave economically viable MRR. Also, this rate had high marketable number of tubers and yield. Therefore, it can be concluded that the application of 110 to 90 kg ha^{-1} nitrogen and phosphorous and can be used by farmers and other stakeholders for the studied areas.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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