Eth.J.Sci & Technol. 5(2):90-98, 2008 ISSN 1816-3378

Performance Stability Analysis of Potato Varieties under Rainfed and Irrigated Potato Production Systems in Northwestern Ethiopia

Yigzaw Dessalegn[1*], Fentahun Mengistu[1] and Tesfaye Abebe[2]
[1]*Amhara Region Agricultural Research Institute, PO Box 527, Tel. 058-220-6400, Bahir Dar*
[2]*Adet Agricultural Research Center, PO Box 8, Tel. 058-338-0237, Adet*
[*]*Corresponding author: yigzawdessalegn@yahoo.com*

Abstract
In Ethiopia, farmers cultivate potato both in the rainy season under rainfed condition and the dry season using irrigation. Despite the variation in climatic condition and production constraints between the two systems, farmers grow the same variety both in rainfed and irrigated potato production systems. Moreover, researchers release improved varieties only based on performance under rainfed production system. Therefore, the objective of this study was to assess the stability of improved potato varieties across the two potato production systems. Nine potato varieties were evaluated using randomized complete block design with three replications under irrigation and rainfed conditions for two consecutive years at Adet Agricultural Research Center, northwestern Ethiopia. Results revealed that improved varieties performed better in the rainfed production system than the irrigated production system. In addition, there was no stable variety in both production systems. Zengena, CIP384321.3, Genet, Wochecha, Guasa, Tolcha and Menagesha had regression coefficients higher than unity indicating that these varieties prefer favorable condition (rainfed potato production system). The local variety and Awash had regression coefficient less than unity indicating their response to the unfavorable condition (irrigated potato production system). This depicts the relevance of fostering independent variety selection program for each potato production system. However, currently varieties such as Zengena and Guasa can be recommended for both production systems.

Key words: Potato; variety; yield; rainfed; irrigation; stability; Ethiopia

1. Introduction
Potato (*Solanum tuberosum* L.) is one of the most important vegetable crops grown in the high and mid altitude areas of Ethiopia. It serves as food and cash crop for small scale farmers, occupies the largest area compared to other vegetable crops and produces more food per unit area and time compared to cereal crops. In 2001 E.C., 0.94 million tons of potato tuber was produced nationally from 164 thousand ha of land (CSA, 2003). The Amhara National Regional State contributed 36.1% of the annual national potato production. However, the regional average potato tuber yield (4.8 t/ha) is less than the national average yield (5.7 t/ha) (CSA, 2003). Factors such as late blight (*Phytophtora infestans*) and bacterial wilt (*Pseudomonas solanacearum*) infections, poor crop management and shortage of adaptable and high yielding varieties contributed to the low productivity of potato in the region (Tesfaye and Yigzaw, 2008).

In Ethiopia potato is produced in the rainy season under rainfed condition and dry season using irrigation. In 2002, the irrigated potato production system contributed 58.7% of the annual potato tuber produced and 76.8% of the total area of land planted with potato in the country (CSA, 2003). Likewise, in the Amhara National Regional State, irrigated potato production system contributed 84.2% of the area and 65.5% of the annual potato production. Although irrigated potato production system contributed the lion's share both in the country and the region, its productivity (3.7 t/ha) is lower than the rainfed (10.5 t/ha) system (CSA, 2003). This could be due to differences in climatic conditions and production constraints of the two production systems. Furthermore, researchers have never released improved varieties for the irrigated potato production system.

The prevailing average monthly maximum temperature is higher in the irrigated potato production system than in the rainfed system. The average monthly minimum temperature is low and causes frost injury to the plant during the irrigated potato production system. Therefore, irrigated potato production is affected both by the prevailing higher maximum and lower minimum temperature compared to the rainfed potato production system (Fig.1). On the other hand, in contrast to the irrigated system, the rainfed potato production system is more affected by late blight.

A temperature of about 20^{o}C is ideal for potato tuber development (Mondal and Chatterjee, 1993). At higher temperatures the plant fails to initiate tuber formation and at low temperatures vegetative growth is restricted by frost (Horton, 1987). Similarly, Mondal and Chatterjee (1993) reported that tuber initiation starts early at lower than at higher temperatures. Besides, the number of tubers produced per plant is higher at lower than at higher temperature. The seed tubers produced at higher temperatures (34^{o}C) are low yielding compared to seed tubers produced at cooler temperatures (7.7^{o}C) (Mondal and Chatterjee, 1993). Therefore, temperature affects not only the yield of treated plants but also the productivity of its progeny.

Bhagsari *et al.* (1988) reported significant variations among potato genotypes in tuber setting and harvest index in different subtropical environments. Despite significant climatic variation between the two systems, potato breeders in Ethiopia select and release improved potato varieties solely based on performance under rainfed condition.

Yield is a complex trait in potato and is generally considered to have low heritability (Lynch and Kozub, 1991). Hence, indirect selection could be useful strategy to bring considerable genetic improvement on potato tuber yield. Therefore, knowledge on the interrelationships of characters with tuber yield seems very important for high yielding potato variety development. Thus, this experiment was conducted to assess the stability of potato varieties and to evaluate the association of different characters with tuber yield under the two potato production systems.

2. Materials and Methods

The performance of nine potato varieties was assessed in this study. The experiment was conducted at Adet Agricultural Research Center using a Randomized Complete Block Design with three replications both under rainfed and irrigated potato production systems for two consecutive years (2001 & 2002). Plot size was 9 m^2 (3 m × 3 m) with a spacing of 75 cm between rows and 30 cm between plants. The trial was planted in the first week of June for the rainfed production system and in the second week of November for the irrigated production system. In both systems nitrogen and P_2O_5 were applied at rates of 81 and 69 kg/ha, respectively. The whole P_2O_5 was applied at planting. The nitrogen split equally into three and was applied at planting, at the first ridging and at flowering. All other crop management practices were applied as recommended.

Number of main stems per plant, plant height, number of tubers harvested per plot, marketable tuber yield, unmarketable tuber yield and total tuber yield were recorded and subjected to analysis of variance using MSTAT-C statistical software. Genotype x production system and genotype x year interaction were assessed using combined analysis of variance. Duncan Multiple Range Test (DMRT) was employed to separate means. Stability analysis was performed following Eberhart and Russell (1966) method using the model $Yij = \mu I + \beta iIj + \delta ij$. Regression coefficient (bi) was considered as a parameter of response and deviation from regression (Sdi^2) as a parameter of stability (Singh and Chaudhary, 1977). Simple linear correlation was computed to evaluate the association of different traits at different potato production systems.

3. Results and Discussion

In the irrigated potato production system, genotypes were significantly different in number of main stems per plant, plant height, number of tubers harvested per plot, marketable tuber yield, unmarketable tuber yield and total tuber yield (Table 1). Zengena was the tallest in plant height among evaluated genotypes. It also had maximum number of main stems per plant and maximum number of tubers harvested per plot among evaluated genotypes. Marketable tuber yield ranged from 6.7 t/ha to 22.2 t/ha. The lowest and the highest marketable tuber yield were recorded from Wochecha and CIP384321.3, respectively. Zengena and CIP384321.3 were not statistically different in marketable tuber yield. Therefore, Zengena and CIP384321.3 seem promising varieties for irrigated potato production system at Adet. Similarly, Bhagsari *et al.* (1988) reported significant variation among potato genotypes in tuber setting and harvest index while grown in different subtropical environments. Elobu and Osiru (1994) also observed significant marketable tuber yield difference among three heat tolerant potato genotypes under a hot lowland tropical condition of Uganda.

In the irrigated potato production system, the maximum temperature was very high and the minimum temperature was very low. High yielding genotypes had maximum number of main stems per plant, high number of tubers per plant and long plant height. Therefore, genotypes difference in marketable tuber yield under irrigated potato production system could be ascribed to their difference in capacity to initiate tuber at higher temperature and frost tolerance. Likewise, Thornton *et al.* (1996) reported that high temperature retarded vegetative and tuber growth rate in potato. Similarly, Horton (1987) reported that at high temperatures, the potato plant fails to initiate tuber and at low temperature its vegetative growth is retarded by frost. In the rainfed potato production system, genotypes significantly varied in plant height, number of tubers harvested per plot, marketable tuber yield, unmarketable tuber yield and total tuber yield (Table 1). Unlike in the irrigated potato production system, genotypes were not statistically different in number of main stems per plant. Marketable tuber yield ranged from 1.44 t/ha to 33.1 t/ha. The local variety was the shortest and had the lowest marketable tuber yield compared to all evaluated varieties. The low productivity of the local variety is ascribed to its susceptibility to late blight. On the other hand, Zengena was the tallest variety and ranked first in marketable tuber yield, but it was not significantly different from CIP384321.3 and Guasa in marketable tuber yield.

Therefore, Zengena, CIP384321.3 and Guasa appeared to be promising varieties for the rainfed potato production system at Adet.

.

Table 1. Mean tuber yield and other agronomic characters of nine potato varieties under irrigated and rainfed potato production systems at Adet, northwestern Ethiopia, in 2001 and 2002.

Variety	Main stems per plant	Plant height (cm)	Tubers harvested per plot	Marketable tuber yield (t/ha)	Unmarketable tuber yield (t/ha)	Total tuber yield (t/ha)
			Irrigated			
Tolcha	3.9c	30.6d	97.0bc	9.66def	5.99abc	15.65cd
Awash	3.7c	35.3cd	141.3ab	12.90cde	7.50ab	19.50bcd
Genet	4.0bc	34.4cd	163.3a	14.56c	7.52ab	22.12abc
Guasa	5.8a	42.4bc	181.3a	16.02bc	8.90a	24.93ab
Local	4.6abc	34.2cd	153.8a	13.62cd	2.53c	16.15cd
Wochecha	4.2bc	32.0d	78.2c	6.72f	5.97abc	12.69d
Menagesha	4.9abc	46.7b	74.0c	8.25ef	5.72abc	13.97d
CIP384321.3	5.6ab	51.5ab	179.7a	22.19a	5.54abc	27.73a
Zengena	6.1a	59.6a	193.7a	19.65ab	4.19bc	23.85ab
Mean	4.8	40.7	140.3	13.63	5.99	19.62
CV (%)	19.9	14.5	22.2	19.5	47.2	22.4
			Rainfed			
Tolcha	4.8	45.8def	160.0abc	20.90bcd	4.95b	25.85cd
Awash	4.7	42.7ef	130.8c	14.25d	2.95bc	17.20e
Genet	5.2	53.3cd	207.3a	24.62b	2.66bc	27.27cd
Guasa	4.7	56.2bcd	183.0ab	26.88ab	5.57b	32.44bc
Local	5.0	38.2f	111.5c	1.44e	0.55c	1.99f
Wochecha	4.8	51.5cde	153.0bc	21.80bcd	2.39bc	24.19d
Menagesha	3.9	57.3bc	112.0c	17.19cd	3.55bc	20.73de
CIP384321.3	3.3	65.3ab	182.0ab	27.68ab	13.31a	40.99a
Zengena	4.2	74.8a	201.2ab	33.10a	2.11bc	35.20ab
Mean	4.5	53.9	160.1	20.87	4.23	25.09
CV (%)	23.2	12.4	19.5	21.6	65.4	16.1

*Means followed by the same letter (s) within a column are not statistically different; each value in the table is mean of 6 observations; * and ** stand for significance at $p\leq0.05$ and $p\leq0.01$, respectively; NS stands for not significant at $p\leq0.05$*

According to across systems and years average performance, varieties were significantly different in plant height, number of tubers harvested per plot, marketable tuber yield, unmarketable tuber yield and total tuber yield (Table 2). Zengena and the local variety gave the highest and lowest marketable tuber yield, respectively. In addition, results of combined analysis of variance showed that marketable tuber yield was significantly different between production systems (Table 2). The rainfed potato production system gave the highest average marketable tuber yield than the irrigated system (Table 2). This could be due to the prevailing average monthly maximum temperature, which was higher in irrigated potato production system than in the rainfed potato production system (Fig. 1). In agreement to this result, Mondal and Chatterjee (1993) reported lower potato tuber yield in warm condition than in cool condition. In addition, tuber initiation delays at higher than lower temperature (Mondal and Chatterjee, 1993). Moreover, higher temperature reduces tuber growth rate (Thornton et al., 1996). The average monthly minimum temperature was also lower in the irrigated than in the rainfed potato production system (Fig. 1). Low temperature retards vegetative growth and subsequently the productivity of the crop. Therefore, low productivity of potato in irrigated potato production system could also be attributed to the prevailing very low minimum temperature. Combined analysis of variance showed that variety × production system, variety × year and variety × system × year interaction effects were statistically significant (Table 3). That was an indication for different varietal response to the changes in growing conditions or environments.

Table 2. Across years and systems mean agronomic and tuber yield performance of nine potato varieties at Adet (2001 & 2002)

Variety	Main stems per plant	Plant height (cm)	Tubers harvested per plot	Marketable tuber yield (t/ha)	Unmarketable tuber yield (t/ha)	Total tuber yield (t/ha)
Tolcha	4.4	38.2ef	128.5b	15.28d	5.47bc	20.75de
Awash	4.2	39.0ef	136.1b	13.13d	5.23bc	18.35e
Genet	4.6	43.9de	185.3a	19.59c	5.11bc	24.69cd
Guasa	5.3	49.3cd	182.2a	21.45bc	7.23ab	28.68bc
Local	4.8	36.2f	132.7b	7.53e	1.54d	9.07f
Wochecha	4.5	41.7ef	115.6bc	14.26d	4.18cd	18.44e
Menagesha	4.4	52.0bc	93.0c	12.72d	4.63bc	17.35e
CIP384321.3	4.5	58.4b	180.8a	24.93ab	9.43a	34.36a
Zengena	5.1	67.2a	197.4a	26.38a	3.15cd	29.53b
Mean	4.6	47.3	150.2	17.25	5.11	22.36
CV (%)	21.5	13.3	20.8	21.4	54.7	18.8

Means followed by the same letter(s) within a column are not statistically different
*Each value in the table is mean of 12 observations; * and ** stand for significance at $p \leq 0.05$ and $p \leq 0.01$, respectively; NS stands for non-significant at $p \leq 0.05$*

Therefore, stability analysis was performed to identify a relatively stable variety among evaluated genotypes.A variety is said to be stable and adaptive if it has high mean yield, about unity regression coefficient and minimum deviation from regression (S^2di). Accordingly, the local variety was the most unstable variety. Zengena, CIP384321.3, Genet, Wochecha, Guasa, Tolcha and Menagesha had regression coefficients higher than unity indicating that these varieties prefer favorable condition (Table 4). The local variety and Awash had regression coefficients less than unity indicating their response to the unfavorable condition. Therefore, there is no stable variety among evaluated genotypes to recommend for production in both systems. Similarly, Abalo *et al*. (2003) reported instability in marketable tuber yield among potato genotypes grown at different localities of Uganda. Hence, independent variety selection program is suggested for each potato production system.

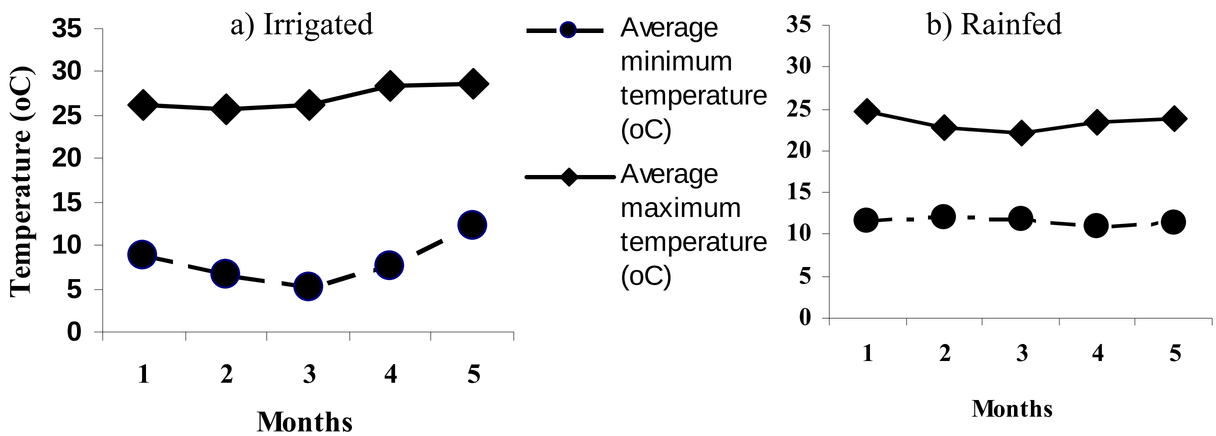

Fig. 1. Average monthly minimum and maximum temperatures during the a) irrigated and b) rainfed potato production systems at Adet.

Table 3. Combined Analysis of variance (ANOVA) on stem number, plant height, days to maturity, number of tubers harvested, marketable, total and unmarketable tuber yields

Source of variation	No. of main stems/ plant	Plant height (cm)	Days to maturity	No. of tubers/ plot	Marketable tuber yield (t/ha)	Un-marketable tuber yield (t/ha)	Total tuber yield (t/ha)
Year (Y)	**	**	**	NS	*	**	*
Systems (s)	*	**	**	**	**	**	**
Y x S	NS	**	**	**	**	**	NS
Variety (V)	NS	**	**	**	**	**	**
Y x V	NS	**	**	**	**	**	NS
S x V	*	**	**	**	**	**	**
YSV	**	**	**	**	**	**	NS

** and ** stand for significance at p≤0.05 and p≤0.01, respectively; NS stands for not significant at p≤0.05*

Table 4. Stability parameters for nine potato varieties in two years and production seasons (rainfed and irrigated) at Adet, northwestern Ethiopia, in 2001 and 2002.

Variety	Regression coefficient (bi)	Deviation from regression (S^2di)	Coefficient of determination	Mean marketable tuber yield (t/ha)
Tolcha	1.09	0.41	0.78	15.28
Awash	0.89	0.63	0.49	13.13
Genet	1.20	0.17	0.96	19.59
Guasa	1.12	0.57	0.66	21.45
Local	-0.64	1.07	0.15	7.53
Wochecha	1.19	0.87	0.49	14.26
Menagesha	1.09	0.18	0.95	12.72
CIP384321.3	1.37	0.61	0.72	24.93
Zengena	1.69*	0.15	0.98	26.37

* stands for significant difference from unity at 5% probability

Knowledge of correlations among different characters is vital to design an effective breeding program. Most economically important traits such as tuber yield are quantitatively inherited. The phenotypic expression of such traits is highly influenced by genotype × environment interaction effect. Consequently, it is very difficult and time consuming trying to improve tuber yield through direct selection. Hence, it is very important to estimate the degree of association of various highly heritable and easily measurable agronomic characters with yield. Simple linear correlation analysis was performed to assess the association of different characters under irrigated and rainfed potato production systems.

In the irrigated potato production system, marketable tuber yield showed positive and statistically significant association with number of main stems per plant, plant height and number of tubers harvested per plot (Table 5). De la Morena *et al.* (1994) also indicated that variation in tuber yield among cultivars was associated with the density of stems. In support of this observation, Baye Berihun *et al*. (2005) reported a considerably high positive correlation between tuber yield per plant and leaf area per plant at genotypic level. Therefore, these traits can be employed as indirect selection index for higher marketable tuber yield. Marketable tuber yield had positive and statistically significant association with plant height and number of tubers harvested per plot in rainfed potato production system (Table 5). This result revealed the importance of sink source ratio in both production systems. In the irrigated potato production system frost retards vegetative growth consequently tuber yield showed strong and positive association with number of main stems. On the other hand, in the rainfed potato production system the prevailing environment favors proliferation of main stem, subsequently showed negative correlation with marketable tuber yield. However, plant height and number of tubers harvested per plot showed positive correlation coefficient with marketable tuber yield in both systems and can serve as indirect selection index for higher marketable tuber yield in both production systems.

4. Conclusion

Varieties gave lower yield in the irrigated system than in the rainfed, suggesting variable responses in different systems. Therefore, it is suggested to commence independent variety development program for each system. Plant height and number of tubers harvested per plot showed positive and statistically significant association with marketable tuber yield, which could be used as indirect selection index for high marketable tuber yield.

5. Acknowledgements

Authors are indebted to horticulture research division of Adet Agricultural Research Center technical assistants. We are also grateful to the financial support of the Amhara Region Agricultural Research Institute, Bahir Dar, Ethiopia.

Table 5. Simple linear correlation coefficients among different traits of potato under different potato production systems, across systems and years at Adet

Traits	Plant height	Tubers harvested per plot	Marketable tuber yield	Unmarketable tuber yield	Total tuber yield
Rainfed					
Main stems per plant	-0.64	-0.03	-0.37	-0.73*	-0.54
Plant height		0.64	0.85**	0.39	0.82**
Tubers harvested per plot			0.85**	0.31	0.79**
Marketable tuber yield				0.43	0.96**
Unmarketable tuber yield					0.68*
Irrigated					
Main stems per plant	0.87**	0.58	0.69*	-0.09	0.61
Plant height		0.50	0.68*	-0.13	0.59
Tubers harvested per plot			0.92**	0.07	0.90**
Marketable tuber yield				-0.05	0.94**
Unmarketable tuber yield					0.31
Across years and seasons					
Main stems per plant	0.43	0.61	0.45	-0.09	0.34
Plant height		0.54	0.82**	0.27	0.74*
Tubers harvested per plot			0.83**	0.33	0.76*
Marketable tuber yield				0.56	0.97**
Unmarketable tuber yield					0.74*

** and ** stand for significant at p≤0.05 and p≤0.01, respectively*

6. References

Abalo G, Hakiza JJ, El Bedewy R and Adipala E (2003). Genotype × environment interaction studies on yields of selected potato genotypes in Uganda. *African Crop Science Journal. 11 (1): 9-15.*

Baye Berihun, Ravishankar R and Harijt S (2005). Variability and associations among tuber yield and related traits in potato. *Ethiopian Journal of Agricultural Sciences. 18:103-121.*

Bhagsari AS, Webb RE, Phatak SC and Jororski CA (1988). Canopy photosynthesis, stomatal conductance and yield of Solanum tuberosum grown in warm climate. *American Potato Journal. 65: 393-406.*

CSA (2003). Ethiopian Agricultural Sample Enumeration, 2001/2002. *Statistical report on socio economic characteristics of the population in agricultural households, land use, area and production of crops, Part I.* Addis Ababa, Ethiopia.

De La Morena I, Guillen A and Garcia Del Moral LF (1994). Yield development in potatoes as influenced by cultivar and the timing and level of Nitrogen fertilization. *American Potato Journal. 71: 165-173.*

Eberhart SA and Russel WA (1966). Stability parameters for comparing varieties. *Crop Science. 6: 36-40.*

Elobu P and Osiru DSO (1994). Performance of three potato (*Solanum tuberosum* L.) genotypes in relation to plant population and applied nitrogen in a lowland area of Uganda. *In the proceedings of the 5th Triennial Symposium of the International Society for Tropical Root Crops, Kampala, Uganda 22-28 Nov. 1992. pp 181-184.*

Horton D (1987). *Potatoes: production, Marketing and Programs for Developing Countries. West view press, Colorado. pp 243.*

Lynch DR and Kozub GC (1991). The association between potato tuber yield and the components of yield in irrigated and dry land environments in the Prairies. *Canadian Journal of Plant Sciences. 71: 279-287.*

Mondal SS and Chatterjee BN (1993). Potao. In: Bose TK, Som MG, Kabir J (eds). Vegetable crops. Naya Prokash, Calcutta, India. pp. 382 - 469.

Singh RK and Chaudhary BD (1977). Biometrical methods in quantitative genetic analysis: Stability models. Kalyani Publishers, Ludhiana, India. pp. 239 – 266.

Tesfaye Abebe and Yigzaw Dessalegn (2008). Review of crop improvement research achievements and future focus in parts of Western Amhara Region: the case of Adet. *In: Tesfaye Abebe (ed.) proceedings of the 1st Amhara Region Regional Workshop on potato research and development achievements and transfer experiences and future directions Bahir Dar, Ethiopia, 20-21 Dec. 2007. pp 85-101.*

Thornton MK, Malik NJ and Dwellee RB (1996). Relationship between leaf gas exchange characteristics and productivity of potato clones grown at different temperatures. *American Potato Journal.* 73 (2): 63-77.