Annals of Tropical Research 42 (2):30-42(2020)

Application of Mitscherlich-Bray equation to formulate fertilizer recommendations for sweetpotato in Leyte, Philippines

Luz G. Asio[1*] and Nenita E. de la Cruz[2]

ABSTRACT

Submitted: 23 March 2020 | Accepted: 28 July 2020

Until now, no studies have been conducted in the Philippines on the use of the Mitscherlich-Bray equation to formulate NPK fertilizer recommendation for sweetpotato. This study used the Mitscherlich-Bray equation to formulate NPK requirements for sweetpotato. Independent experimental set-ups of N (7 application levels), P (6 levels), and K (9 levels) arranged in RCBD with three replications were simultaneously conducted. Theoretical maximum yield, NPK constants c_1 and c, NPK fertilizer recommendations for sweetpotato at different soil fertility levels, and optimum fertilizer rates were calculated. Fertilizer recommendations for a common range of soil test values were developed but needed further field verification trials. Theoretical maximum yields determined by the Mitscherlich-Bray equation were 19.05, 12.66, and 14.88t ha^{-1} for NPK, respectively. The study showed that inherent soil fertility is vital in the development of fertilizer recommendation for sweetpotato not only to increase root yield but likewise to increase overall productivity. It showed that 30, 50, and 60 percent of the maximum possible yield was attributed to the inherent soil N, P, and K, respectively. N, P_2O_5, and K_2O recommendations for sweetpotato were computed based on a common range of soil test values ranging from 50 to 300, 5 to 40, and 200 to 700kg ha^{-1} NPK, respectively.

Keywords: sweetpotato, Mitscherlich-Bray equation, NPK, fertilizer recommendations

[1]Department of Agronomy, College of Agriculture and Food Sciences, Visayas State University, Baybay City, Leyte Philippines
[2]Department of Soil Science, Central Luzon State University, Science City of Munoz, Nueva Ecija Philippines

***Corresponding Author.** Address: Department of Agronomy, College of Agriculture and Food Sciences, Visayas State University, Baybay City, Leyte Philippines; Email: luz.asio@vsu.edu.ph
DOI: 10.32945/atr4223.2020

INTRODUCTION

Sweetpotato (*Ipomoea batatas* [L.] Lam.) is considered a smallholder crop in the Philippines. In many instances, it is grown in marginal upland soils with limited inputs (Roa et al 2008, Lebot 2009, Asio et al 2009). Like any other crop, however, its production performance is often better when grown in soils with adequate nutrient supply. Sweetpotato farmers in Leyte, Philippines, use fertilizer rates that are assumed to be adequate due to lack of information on the nutrient requirements of this crop and also due to the skyrocketing prices of fertilizers. These farmers are still constrained by the lack of technical know-how on the use of balanced fertilization (Cabanilla 1996, de la Cruz 2006, Relente & Asio 2020).

Plants respond to inputs of various growth factors. The earliest attempt to relate plant growth to various factors of growth was made in the 1840s by Justus von Liebig, a professor of chemistry at the University of Giessen, Germany (Justus Liebig Gesselschaft zu Giessen 1990). He promulgated his Law of Minimum, which states that growth is dictated not by all the factors of growth available but by the limiting factor and that by adding increments of the limiting growth factor, yields will increase. It says that yield is proportional to the increase of the minimum factor until the theoretical maximum yield is reached (Gisi 1990). This can be expressed mathematically using a linear equation as y=c.x, where y is the yield increase due to nutrient application, x is the amount of nutrient applied, and c is a constant dependent on the nutrient and the soil (Gisi 1990).

The best-known attempt to express growth curves mathematically was the Mitscherlich equation developed by EA Mitscherlich (1874-1956), professor of agronomy in Berlin, Germany. Based on Liebig's Law of Minimum, Mitscherlich developed an equation that related growth to the supply of plant nutrients, which he published in 1909 (Sorensen 1983, Harmsen 2000). He observed that when plants supplied with adequate amounts of all but one nutrient, their growth was proportional to this one limiting nutrient supplied to the soil. The increase in growth with each successive addition of the nutrient in question was progressively smaller (Tisdale & Nelson 1975, Fox 1971). Thus, it became known as the Law of Diminishing Increment (Sorensen 1983). Mathematically this is expressed as dy/dx = (A-y) c, where, dy is the increase in yield from an increment of the growth factor dx, dx is an increment of factor x, dy/dx is the rate of yield increase (slope), A is the maximum possible yield obtained from the growth factors supplied in optimum amounts, y is the yield obtained after a given quantity of factor x was applied, and c is the proportionality constant which depends on the nature of the growth factor (Fox 1971, Tisdale & Nelson 1975, Sorensen 1983). In integrated form, the equation is written as log (A-y)=log(A) – cx. Mitscherlich found that the values of c were 0.122, 0.60, and 0.40 for N, P_2O_5 and K_2O, respectively. But this was criticized by several workers who found that c is not constant but instead varies widely for different crops under different climatic conditions (Tisdale & Nelson 1975).

In 1952, Roger Bray from the University of Illinois modified the Mitscherlich equation to include the native soil test value (b) and its efficiency factor (c_1) (Sonar & Babhulkar 2002, Tisdale & Nelson 1975, Balba & Bray 1956). The Mitscherlich-Bray equation is given as log (A-y)=log A – c_1b – cx.

In 1918, the German mathematician Bernhard Baule (1891-1976), who worked with Mitscherlich, developed the concept of Baule unit for use in the Mitscherlich equation. He proposed that it is not the absolute increase in yield that reflects the effect of fertilization, but the percentage increase relative to the maximum possible yield (Munson & Doll 1959, Tisdale & Nelson 1975).

In practice, the Mitscherlich-Baule equation says that when one Baule unit of a nutrient is added, the yield increases 50% of the difference between current yield and maximum possible yield. If a second Baule unit is added, then yield increase will be 1/2-way closer to the maximum possible yield, so 2 Baule units would result in 75% of the maximum possible yield increase. If a third Baule unit of a nutrient is added, it will move 1/2-way closer to the maximum possible yield, or 87.5% of the maximum possible yield would result (Munson & Doll 1959). Judicious fertilizer use is inevitable if optimum crop yields are to be realized and sustained.

Until now, no studies have yet been conducted in the Philippines on the use of the Mitscherlich-Bray equation to formulate NPK fertilizer recommendations for sweetpotato. The existing blanket fertilizer recommendation of 40-40-60kg N, P_2O_5 and K_2O from the Philippine Root Crop Research and Training Center (Philrootcrops) needs evaluation.

MATERIALS AND METHODS

The experimental site of the Department of Agronomy used had been previously planted with corn, legumes (peanut, cowpea, beans) and sweetpotato. It was well-drained developed from alluvial sediments of volcanic origin (basalt & andesitic rocks) with an elevation of 5-10m ASL and having an annual rainfall of 2,800mm and air temperature of between 25-29°C (Coronas' Type 1V Climate). The soil classified as Umingan sandy loam (Inceptisol) had 12% clay, 21% silt, and 67% sand. A uniformity trial using corn was done to minimize spatial variation in soil fertility before the conducting of the experiment. The soil had a pH (1:2.5 soil: water ratio) of 5.87-5.90 optimal (5.5 to 6.5) for sweetpotato (Nedunchezhiyan & Ray 2010). It had low soil organic matter (3.4%), sufficient total N (0.21%), high available P (19mg kg^{-1}), and high exchangeable K (0.94me 100^{-1}g soil) (Landon 1991).

Independent experimental set-up of N (7 levels: 0, 40, 80, 120, 160, 200, 240kg ha^{-1} N), P (6 levels: 0, 20, 40, 60, 80, 100kg ha^{-1} P_2O_5) and K (9 levels: 0, 30, 60, 90, 120, 160, 200, 240, 280kg ha^{-1} K_2O) arranged in RCBD with three replications were simultaneously conducted. Plot size was $18m^2$ (3mx6m) and alleyways of 1.0m between replications and 0.75m between plots to facilitate experimental operations. The treatments were based on the recommended fertilizer rate of Philrootcrops at VSU (Visayas State University) of 40-40-60kg ha^{-1} N, P_2O_5, K_2O. Apical vines of a traditional sweetpotato var Siete Flores were planted at 0.75m between rows and 0.25m between hills (53,333.33 plants ha^{-1}). This variety is popular and the most preferred by local consumers due to its good eating quality (sweet, mealy & sturdy); however, this is generally known to be low yielding at about 3.5t ha^{-1} (Cabanilla 1996). Urea and muriate of potash were applied in split doses at planting and side dressed 6 WAP. Blanket application of the whole amount of solophos was applied at planting. Split application of K to sweetpotato is recommended especially for late-maturing varieties (>22 weeks) like Siete Flores to provide this nutrient in the later stage of sweetpotato growth for root development.

Pheromone traps were set in the field instead of chemical insecticide to control weevils (Vasquez et al 2009). Harvesting was done by manual digging of roots 25 WAP. Plant growth and yield and yield parameters were measured such as the length of the main vines, the number of primary lateral vines, fresh herbage weight, dry matter yield (t ha^{-1}), number of marketable and non-marketable roots, total root yield (t ha^{-1}), percentage of marketable roots $plot^{-l}$ and root size (mm) $plot^{-1}$.

The root yield data collected were subjected to the Mitscherlich-Bray equation as given below (Sonar & Babhulkar 2002, Afzal et al 2014).

$$\log(A - y) = \log A - c_1 b - cx$$

where A=% theoretical maximum yield; y=is actual yield in kg ha^{-1}; b=is the native soil test in kg ha^{-1}; x=nutrient fertilizer applied in kg ha^{-1}; c_1 and c=are constants, ie, efficiency of soil test value and fertilizer nutrient, respectively. (c_1=inherent soil nutrient based on soil test results; c=nutrient applied in the form of fertilizer).

Using the method of Sonar and Babhulkar (2002) and Afzal et al (2014), the following parameters were calculated from the above equation:

I. Theoretical maximum yield by plotting log y against 1/x

II. Constants c_1 and c for N, P, and K calculated separately following the equation.

$$c_1 = \log A - \log(A - y_o) / b$$

where y_o = yield obtained from control plots

$$c = (\log A - c_1 b) - \log(A - yx) / x$$

where yx = yield obtained at fertilizer dose x

III. Fertilizer N, P, and K recommendations for sweetpotato at different soil fertility levels were calculated following the equation below:

$$x = \log(A - c_1 b) - \log(A - yx) / c$$

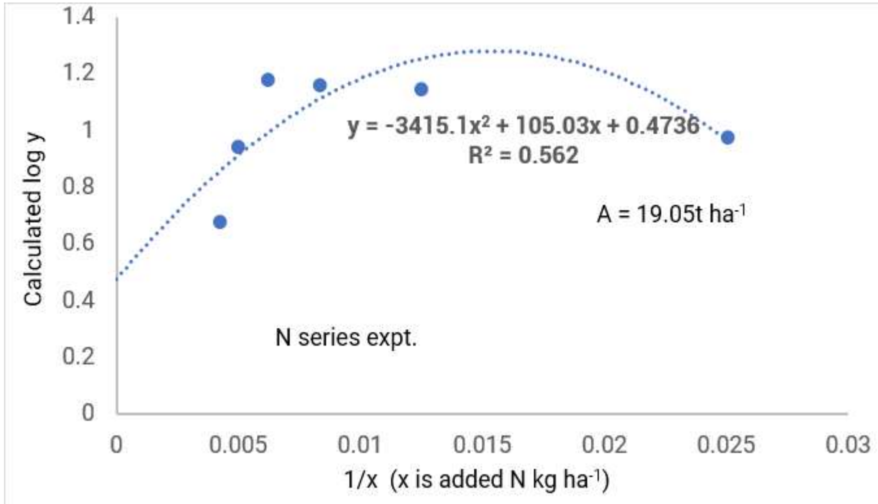
where yx = yield obtained at fertilizer dose x

RESULTS AND DISCUSSION

The actual root yield of sweetpotato from the three experiments was used to calculate the terms of the Mitscherlich-Bray, such as the log y, 1/x, $c_{1,}$ and c (Table 1). Using the equation, the theoretical maximum yields calculated were 19.05t ha^{-1}, 12.66t $ha^{-1,}$ and 14.88t ha^{-1} for the N, P, and K experiments, respectively, obtained from the plot of log y against 1/x (Figure 1). The c_1 and c values were 0.00172 and 0.002881 for N, 0.00736, and 0.014486 for P and 0.000502 and 0.001838 for K, respectively. The c_1 value for K was smaller compared to the c_1 values of N and P, which means that soil K was less efficiently utilized by the sweetpotato compared to soil N and soil P. The ratio c1/c indicates the response of sweetpotato to fertilizer application. A higher ratio value means that the crop has a lesser response to the applied fertilizer, while a lower ratio value indicates greater response of the crop to the applied fertilizer (Sonar & Babhulkar 2002). The ratio c1/c of the K experiment was the lowest compared to the c1/c ratio values of the N and P experiments, indicating that sweetpotato was more responsive to K fertilization than N and P fertilization. The result confirms the widely held view that sweetpotato is responsive to K fertilization (Marschner 1995, O'Sullivan et al 1997, Lebot 2009).

Table 1. Sweetpotato yields and efficiency coefficients of soil and fertilizer NPK

Treatments	Actual yield (y) t ha^{-1}	Calculated log y	1/x	c_1	c	c_1/c
N applied, kg ha^{-1}				0.00172		
0	5.39					
40	9.51	0.978	0.0250		0.003898	
80	14.03	1.147	0.0125		0.005434	
120	14.41	1.159	0.0083		0.003908	
160	15.31	1.185	0.0062		0.003516	0.597
200	8.72	0.940	0.0050		0.000607	
240	4.79	0.680	0.0042		(0.000078)	
Mean					0.002881	
Theoretical max. yield	19.05					
P_2O_5 applied, kg ha^{-1}				0.00736		
0	6.02					
20	12.25	1.088	0.0500		0.060469	
40	9.68	0.985	0.0250		0.008699	
60	7.19	0.857	0.0170		0.001403	0.508
80	7.73	0.888	0.0125		0.001617	
100	6.45	0.809	0.0083		0.000242	
Mean					0.014486	
Theoretical max. yield	12.66					
K_2O applied, kg ha^{-1}				0.000502		
0	8.52					
30	9.33	0.970	0.0330		0.001972	
60	8.31	0.920	0.0170		(0.000235)	
90	10.67	1.028	0.0110		0.001991	
120	12.26	1.088	0.0083		0.003210	
160	10.90	1.037	0.0062		0.001272	0.273
200	10.81	1.034	0.0050		0.000969	
240	14.29	1.155	0.0042		0.004303	
280	11.99	1.079	0.0035		0.001427	
Mean					0.001838	
Theoretical max. yield	14.88					



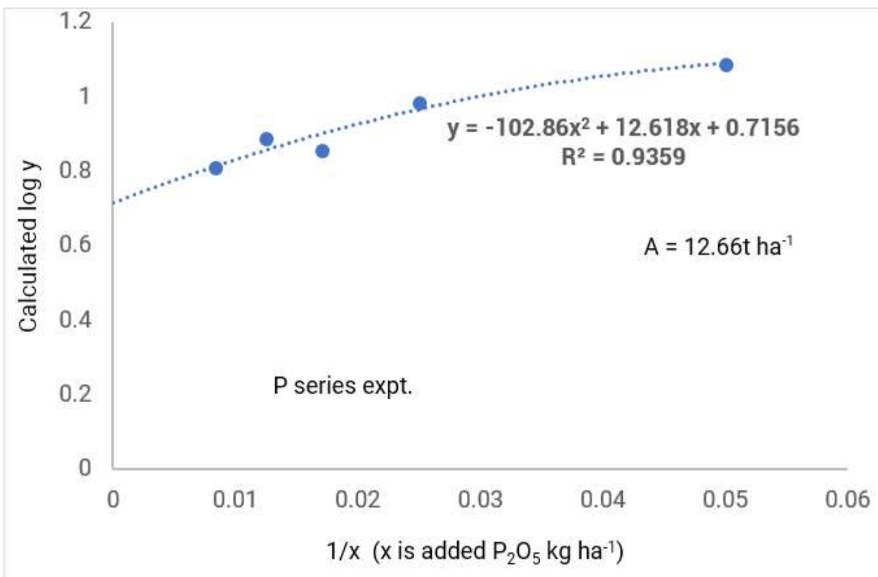


Figure 1. Theoretical maximum yield (A) of sweetpotato from the plot of log y vs. 1/x as affected by levels of NPK application

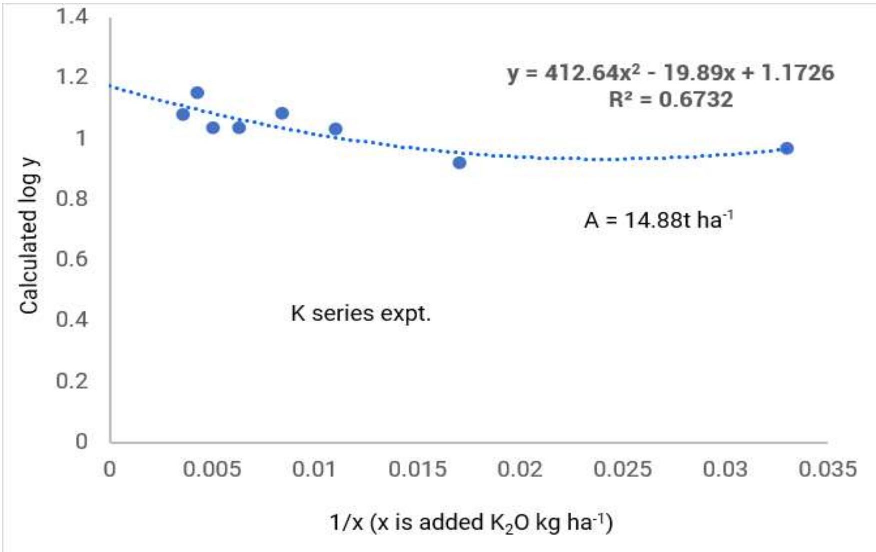


Figure 1 continued

The findings of this study revealed that soil test alone is not a reliable basis for formulating fertilizer recommendations. This is because it was shown that even if the soil contained sufficient amounts of N, P, and K, it was only capable of producing approximately 30, 50, and 60% of the maximum possible yield (Figure 2). The study demonstrated that even if the soil had sufficient inherent amounts of nutrients, fertilization was still necessary for higher root yield.

The widespread practice of using "blanket fertilizer recommendation" for a particular crop regardless of site or soil conditions, is not only erroneous and unscientific, but it is also wasteful. It can lead to under or over fertilizer applications. The former will result in low and unprofitable yield, while the latter will increase production cost and can be detrimental to the environment in the long-term.

The Mitscherlich equation, in its classical or modified form, is a powerful tool for evaluating crop response to fertilization and for formulating fertilizer recommendations. The Mitscherlich-Bray modification incorporates not only crop response to fertilization but soil test values as well, thus, makes the equation more useful in formulating site-specific fertilizer recommendations. According to Dudal and Roy (1995), the design and implementation of integrated nutrient management systems require some forms of conceptual, analytical and simulation models to serve as a framework for the integration of the different components of such management systems. The Mitscherlich equation is a useful tool for such purpose.

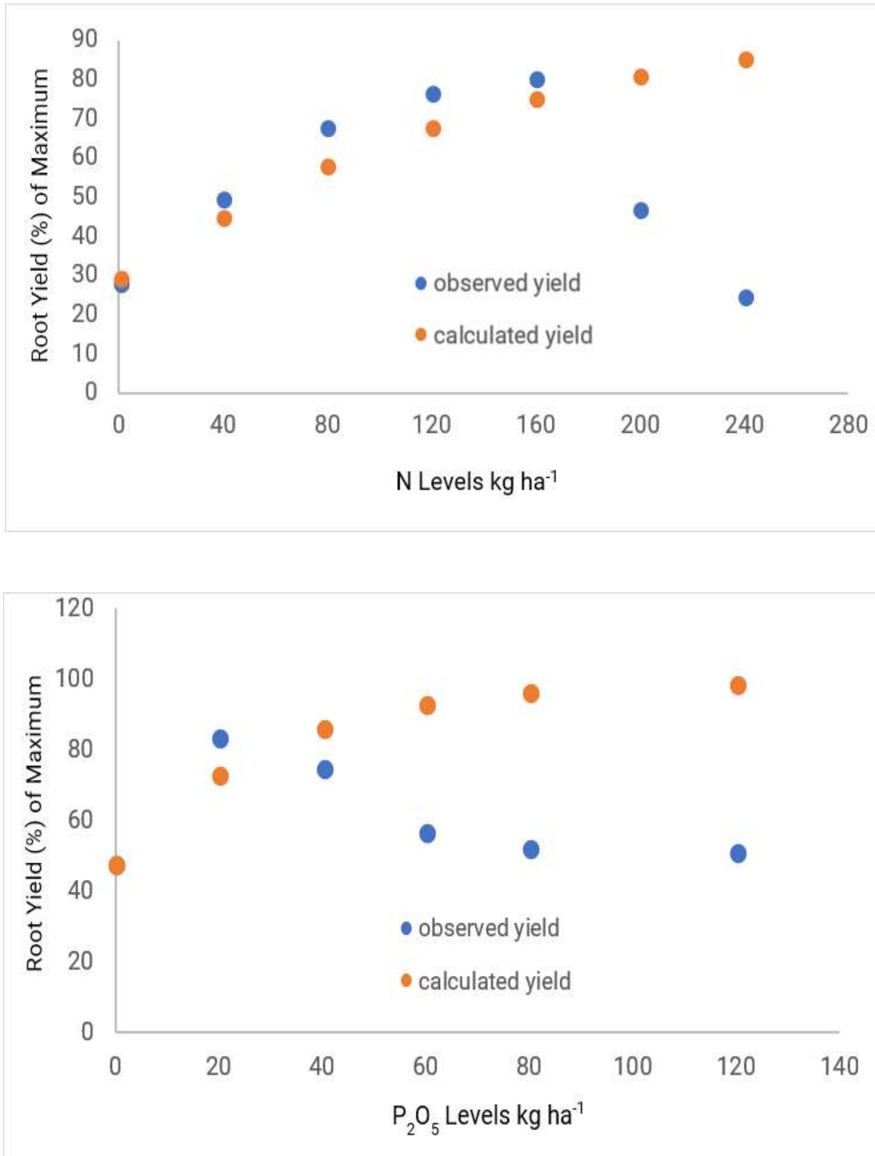


Figure 2. Scatter plot of calculated and actual root yield of sweetpotato expressed as a percentage of the theoretical maximum yield as affected by NPK fertilization.

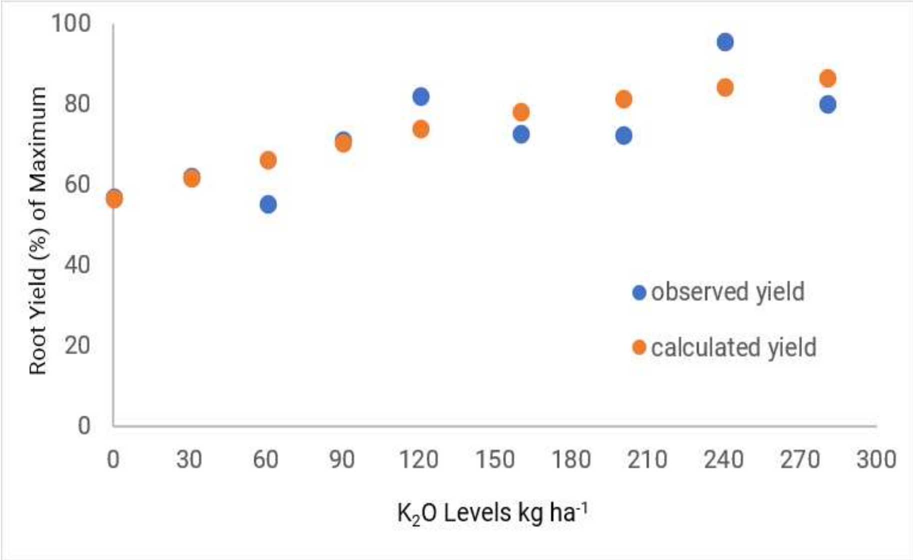


Figure 2 continued

Table 2 shows the fertilizer recommendations derived from the yield data of the three experiments using the Mitscherlich-Bray equation. Fertilizer N, P_2O_5, and K_2O requirements of sweetpotato were computed for a common range of soil test values ranging from 50 to 300kg ha^{-1} N, 5 to 40kg ha^{-1} P, and 200 to 700kg ha^{-1} K. These recommendations could provide a choice for a yield target depending on the inherent soil fertility levels. For example, fertilizer recommendation for a soil with low soil fertility (N=50, P=5, K=200kg ha^{-1}) would be 213kg ha^{-1} N, 46kg ha^{-1} P_2O_5, and 326kg ha^{-1} K_2O to attain 80% of the maximum yield. Although the different fertilizer recommendations are predicted to be effective, verification trials are still necessary, as has been demonstrated by Sonar and Babhulkar (2002) and Afzal et al (2014). The verification stage was not part of the present study and is recommended to be carried out as a follow-up experiment.

Sonar and Babhulkar (2002) and Afzal et al (2014) and many others have successfully used this modified equation for evaluating fertilizer response and the requirements of various crops. In this present study on sweetpotato in Leyte, the approach used by Sonar and Babhulkar (2002), which was also successfully employed by Afzal et al (2014), was used. Specifically, the actual root yield obtained from the three fertilizer experiments (NPK experiments) on a traditional sweetpotato variety Siete Flores was subjected to the Mitscherlich-Bray equation described above.

Results in Table 2 may also be interpreted using the Mitscherlich-Baule concept. According to Baule, it is not the absolute increase in yield that reflects the effect of fertilization, but the percentage increase relative to the maximum possible yield. Thus, he proposed that increases in yield should be measured in percentages rather than as absolute units. In particular, he suggested that the unit of fertilizer, or any other growth factor, be taken as the amount necessary to produce a yield that is 50% of the maximum possible yield. Plants require different absolute amounts of N, P, and K, but amounts (for example, in kilograms) of each required to produce a yield that is 50% of the maximum possible yield is termed as *one Baule unit* (Munson & Doll 1959, Tisdale & Nelson 1975).

Application of Mitscherlich-Bray equation to formulate fertilizer

Table 2. Fertilizer recommendations for sweetpotato based on the Mitscherlich-Bray concept

Soil Available Nutrient (kg ha^{-1})	Percent of Theoretical Maximum Yield				
	50	75	80	85	90
Nitrogen (N)					
50	75	179	213	256	317
100	45	150	183	227	288
150	15	120	154	197	258
200	0	90	124	167	228
250		60	94	137	199
300		31	64	108	169
Phosphorus (P_2O_5)					
5	18	39	46	54	66
10	16	36	43	52	64
20	11	31	38	47	59
30	6	26	33	42	54
40	0	21	28	37	49
Potassium (K_2O)					
200	109	273	326	394	489
300	82	246	298	366	462
400	54	218	271	339	435
500	27	191	244	312	407
600	0	164	216	284	380
700		136	183	257	353

Calculated using the Mitscherlich-Bray equation log(A-y)=log A – c1b – cx; where: A is the theoretical maximum yield, y is the yield obtained from the applied nutrient, x is the fertilizer applied, c is the efficiency of nutrient x, and b is the soil test value.

Thus, from Table 2, one Baule unit of N is 75kg ha^{-1} for soil with 50kg ha^{-1} inherent N (ie, soil test value), 45kg N ha^{-1} for soil with 100kg ha^{-1}, inherent N and others. For P, 1 Baule unit of P is 18kg P_2O_5 ha^{-1} for soil with 5kg ha^{-1} inherent P, 16kg P_2O_5 ha^{-1} for soil with 10kg ha^{-1} inherent P and others. Likewise, for K, 1 Baule unit is 109 kg K_2O ha^{-1} for soil with 200kg ha^{-1} soil K.

Table 3 presents suggested fertilizer recommendations for sweetpotato when using a soil test kit (STK) developed by the University of the Philippines Los Baños. The calculation was based on the low, medium, and high values recommended by Landon (1991). The table shows that farmers can choose the target yield depending on their capability to buy the required fertilizers. For a certain level of soil fertility, the amount of fertilizer to be applied increases with an increase in percent target yield. For example, if the soil fertility level for N is medium; the amount of N fertilizer applied will be 171 to 215kg ha^{-1} N to attain the 80 to 85% maximum possible yield, respectively.

Table 3. Suggested fertilizer recommendations for sweetpotato using soil test kit (STK)

Soil Fertility Level	Percent of Theoretical Maximum Yield				
	50	75	80	85	90
Nitrogen					
low	57	161	195	238	300
medium	33	138	171	215	276
high	0	90	124	167	228
Phosphorus					
low	11	31	38	47	59
medium	6	26	33	42	54
high	0	21	28	37	49
Potassium					
low	121	285	338	406	501
medium	100	263	316	384	480
high	57	221	273	341	437

Calculated using the Mitscherlich-Bray equation for the following soil test values: Total N (%) = 0.2 (low); 0.3 (medium); 0.5 (high). Avail P (ppm) = 10 (low); 15 (medium); 20 (high). Exch. K (me $100g^{-1}$ soil) = 0.2 (low); 0.3 (medium); 0.5 (high) (Source: Landon, 1991)

CONCLUSIONS

N, P, and K recommendations for different soil fertility levels can be determined using the Mitscherlich-Bray equation, which is used as a guide for sweetpotato production. The study has proved that the inherent fertility of the soil considerably affects the yield of sweetpotato. Thus, the use of blanket fertilizer recommendations, as is currently practiced for sweetpotato production in the Philippines, can result in either under or over-application of fertilizers. The study also proved that N, P, and K fertilizer application is still necessary to produce high sweetpotato yields even if the soil contains sufficient amounts of these nutrients based on the soil test. The study further indicates that a soil test is not enough to formulate fertilizer recommendations. The Mitscherlich-Bray equation is useful in understanding the nutrient response of sweetpotato and in formulating fertilizer recommendations. It should, thus, be employed in every soil fertility trial.

ACKNOWLEDGMENT

The authors are grateful for the ASTHRD-NSC doctoral scholarship awarded by the Department of Science and Technology (DOST)-Science Education Institute to the principal author.

REFERENCES

Afzal S, Islam M & Obaid-Ur-Rehman. 2014. Application of Mitscherlich-Bray Equation for Fertilizer Use in Groundnut. *Communication in Soil Science and Plant Analysis* 45(12):1636-1645

Asio VB, Jahn R, Perez FO, Navarrete IA & Abit SM Jr. 2009. A review of Soil Degradation in the Philippines. *Annals of Tropical Research* 31(2):69-94

Balba MA and Bray RH.1956. The application of the Mitscherlich Equation for the calculation of plant composition due to fertilizers increments. *Soil Science Society of America Journal* 20(4):515-518

Cabanilla LS. 1996. Sweetpotato in the Philippines: Production, processing, and future prospects. International Potato Center, Lima, Peru

de la Cruz NE, Aganon CP, Patricio MG, Romero ES, Lindain SA & Galindez JL. 2006. Production of organic fertilizer from solid waste and its utilization in intensive organic-based vegetable production and for sustaining soil health and productivity. Proceedings of the International Workshop on Sustained Management of the Soil-Rhizosphere System for Efficient Crop Production and Fertilizer Use, 16-20 October 2006, Land Development Department, Bangkok Thailand

Dudal R and Roy RN. 1995. Integrated Plant Nutrition Systems. Report of expert consultation, 13-15 December 1993. FAO, Rome, Italy

Fox RL. 1971. Growth Response Curves: The law of diminishing return. Illustrated Concepts in Tropical Agriculture. A series prepared by the Department of Agronomy and Soil Science, College of Tropical Agriculture, University of Hawaii. https://www.ctahr.hawaii.edu/oc/freepubs/pdf/IC-002.pdf

Gisi U, Schenker R, Schulin R, Stadelman F & Stiker H. 1990. Bodenoekologie (Soil Ecology). Thieme Georg Verlag, Stuttgart

Harmsen K. 2000. A modified Mitscherlich equation for rainfed crop production in semi-arid areas: 1. Theory. *NJAS-Wageningen Journal of Life Sciences* 48(3):237-250

Justus Liebig Gesellschaft Zu Giessen. 1990. Symposium "150 Jahre Agrikulturchemie". Giessen, Germany

Landon JR. 1991. Booker Tropical Soil Manual. A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and sub Tropics. Longman Scientific and Technical Publ , Harlon

Lebot V. 2009. Tropical Root and Tuber Crops: Cassava, Sweet Potato, Yams and Aroids. Crop production science in horticulture (17), CAB books, CABI, Wallingford, UK. Springer

Marschner H. 1995. Mineral Nutrition of Higher Plants (2nd edn). Academic Press, London: Limited

Munson RD and Doll JP. 1959. The economics of fertilizer use in crop production. *Advances in Agronomy* 11:133-167

Nedunchezhiyan M and Ray RC. 2010. Sweet potato growth, development, production, and utilization: Overview. In Ray RC and Tomlins KI (eds) *Sweet potato: Postharvest aspects in Food* (pp1-26). Nova Science Publishers Inc., New York

O'Sullivan JN, Asher CJ & Blamey FPC. 1997. Nutrient Disorders of Sweet Potato. Australian Center for International Agricultural Research (ACIAR). Canberra ACT 2601, Australia. ACIAR Monograph No. 48

Relente FC and Asio LG. 2020. Nitrogen application improved the growth and yield performance of sweetpotato (*Ipomoea batatas* L. Lam). *Annals of Tropical Research* 42(1):45-55

Roa J, Kadohira M, Bergantin R, Bolatete DM Jr & Yamauchi A. 2008. Farmers' decision-making strategies on selecting rootcrop varieties in the Visayas Region, Philippines. *Reseach bulletin of Obihiro University* 29:1-12

Sonar KR and Babhulkar VP. 2002. Application of Mitscherlich-Bray Equation for Fertilizer use in Wheat. *Communications in Soil Science and Plant Analysis* 33(15-18):3241-3249

Sorensen RC. 1983. Teaching the characteristics of yield response with the Mitscherlich equation using computers. *Journal of Agronomic Education* 12(1):21-25

Tisdale SL and Nelson WL. 1975. Soil Fertility and Fertilizers. McMillan, New York

Vasquez EA, Schmidt D, Zebitz CP, Beifuss U, Klaiber I, Kroschel J & Patindol R. 2009. Sweetpotato weevil pheromones and their precursors: Dose-response and structure-activity relationship in *Cylas formicarius* Fabr., *Cylas brunneus* Olivier and *Cylas puncticollis* Boheman. *Annals of Tropical Research* 31(2):16-40