RESEARCH ARTICLE

Optimum limestone rates for improved soil fertility and Potato (Solanum tuberosum L.) Yield in two agroecologies zones of Cameroon

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Abstract

Potato (*Solanum tuberosum* L.) is a high demanding crop in terms of nutrient requirements. In Cameroon soil fertility is poorly managed and lead to very low yield. This study estimates the limestone rate required for sustainable soil management and improved potato production in two main potatoes producing agroecological zones (AEZ). Two field experiments carried out in two villages namely Wassande (Guinean high savannah zone (AEZII)) and Bangou (Western Highlands zone (AEZ III)) consisted to plant potato genotypes Dosa and Jacob2005 on a split plot design including unfertilized, NPK-fertilized and NPK+manure-fertilized soils in which limestone was applied 4 weeks before, at 1, 2, 3, 4 and 5 $t.ha^{-1}$(ton per hectare) rates. Data were collected on soil physico-chemical properties and potato yield. Limestone rate increased soil pH (hydrogen potential), organic matter (MO) content, cation exchangeable capacity (CEC) as well as sum of exchangeable bases (SEB), and decreased the Al (aluminum) content. P(phosphorus) and Ca (calcium) content Should be increased with limestone rate but decreased at 5 $t.ha^{-1}$. Potato yield increased with limestone rate on unfertilized soil in both sites. On fertilized soils, the optimum limestone rate was 3 $t.ha^{-1}$ in Wassande and 4 $t.ha^{-1}$in Bangou. There was no significant difference between NPK and NPK+manure fertilized soils at higher limestone rates (3-5 $t.ha^{-1}$) in Wassande, whereas in Bangou, the highest yield was obtained with NPK+manure. Genotype Dosa performed better than Jacob2005 in Wassande but less in Bangou than Jacob2005. The best performance was obtained with 3 $t.ha^{-1}$ of limestone in Wassande and 4 $t.ha^{-1}$ in Bangou.

Keywords: Soil amendment; Potato yield; Limestone rate; Soil fertility; Cameroon

Introduction

Potato (*Solanum tuberosum* L.) is one of the most widely grown vegetable crops in the world (ZHANG et al., 2017). Due to its high content in vitamins and minerals (Ducharme, 2016), potato is considered as a vital crop for food security worldwide (Devaux et al., 2020). It is the world's leading non-cereal foodstuff. Global production of this commodity was estimated at 370.4 million tons in 2019 (FAO, 2020). In Cameroon, potato production contributes to improve the livelihood of farmers. It is grown mainly in three of the five agro-ecological zones of the country including: the Sudano-Sahelian zone, the western highlands and the Guinean high savannah zone (Haaland, 2023). Despite its nutritional and socio-economic importance, potato yield in Cameroon is low (9 $t.ha^{-1}$), with yield gap of 60% between the current yield and the potential yield of 25 $t.ha^{-1}$ (Yengoh and Ardo, 2014). The low productivity of agricultural sector in many parts of Sub-Saharan Africa is largely attributed to low soil fertility. Low soil fertility is related to acid rain, erosion, continuous cropping, soil acidity, organic matter depletion and deterioration of soil biological properties (Nduwumuremyi et al., 2013) ; (Getachew, 2019). In Cameroon, most of the soils have a high leaching potential. This leaching is accompanied by nutrient deficiencies (N, P and K) (Nitrogen-Phosphorus-Potassium) and soil acidification (Djoukeng et al., 2014). In order to increase soil fertility, the use of chemical fertilizers is generally recommended, sometimes in combination with manure (Djoukeng, and. Dogot, 2016). However, recent studies showed that, the use of chemical fertilizers alone even at higher rates do not improve yield when organic matter (OM) is low (Oshunsanya, 2017).

Chemical fertilizers contribute to a decline of soil fertility and crop yields through the destruction of soil microflora and microfauna, as well as the accumulation of Al^{3+} (aluminum ions) ions and nitrates (Oshunsanya, 2017). Chemical fertilizers act on the clay-humus complex, resulting in the desaturation of exchangeable Ca into phytotoxic minerals (Tsozué et al., 2015 ; Tamfuh et al., 2019). According to (Brady and Weil, 2004)), accumulation of Al^{3+} and H^{+}(hydrogen) ions inhibits plant root development and the absorption of essential nutrients. This accumulation gradually becomes toxic and can reduce yields by 3 to 67% (Opala et al., 2015 ; Bekele et al., 2018). Demographic pressure on land has reduced fallow time, exposing soils to erosion and nutrient depletion (Getachew et al., 2014). However, the combination of NPK and manure improves crop yields. (Žydelis et al., 2019) showed that the combined use of manure and mineral fertilizer increases maize yield compared to the application of organic or mineral fertilizer alone. According to (Žydelis et al., 2019), manure has great potential for improving soil nutrient availability.

Solutions have been proposed to manage soil acidity and improve soil fertility; this includes addition of dolomite or limestone to the soil in order to reduce acidity (Basak et al., 2016), reducing Al and H toxicity, hence improving soil pH as well as releasing nutrients retained in the soil colloidal system (Nduwumuremyi et al., 2013). Calcium released by the applied lime forms rigid bonds with the pectic chains and favors the resistance of plant cell walls to enzymatic degradation from pathogens (Fageria and Baligar, 2008). (Charles et al., 1992) reported that in Rwanda, application of limestone doses of up to 4.5 $t.ha^{-1}$ on acid soils resulted in significant increase of wheat, bean and potato production. (Tamfuh et al., 2019) used dolomite in the highlands of Cameroon, to improve the yield of green bean (*Phasoelus vulgaris*). There are many sources of lime (wood ash, dolomite and calcium carbonate) in Cameroon. Cameroon's soils are highly acidic, with a pHwater below that required for potato cultivation (6<pH<6.5). This acidic character contributes to low potato yields. The addition of limestone corrects the pH and therefore breaks the bonds created between nutrients, making them available for plant nutrition and optimal potato production. Calcium carbonate is frequently used by farmers to restore and maintain soil quality. However, each farmer applies limestone at its own rate and this is not efficient for high crop production. There is a need to optimize limestone rate tailored on AEZ for efficient use and high potato production. The aim of this study was to determine the limestone rate required for sustainable soil management and improved potato production under different fertilization types in two agroecological zones of Cameroon.

Material and methods

Study sites

Two field experiments were conducted in Cameroon under different environmental conditions to study the effect of limestone rate on potato genotypes. Experiment 1 was carried out in Wassande and experiment 2 in Bangou. All the experiments were carried out from April to July 2021.

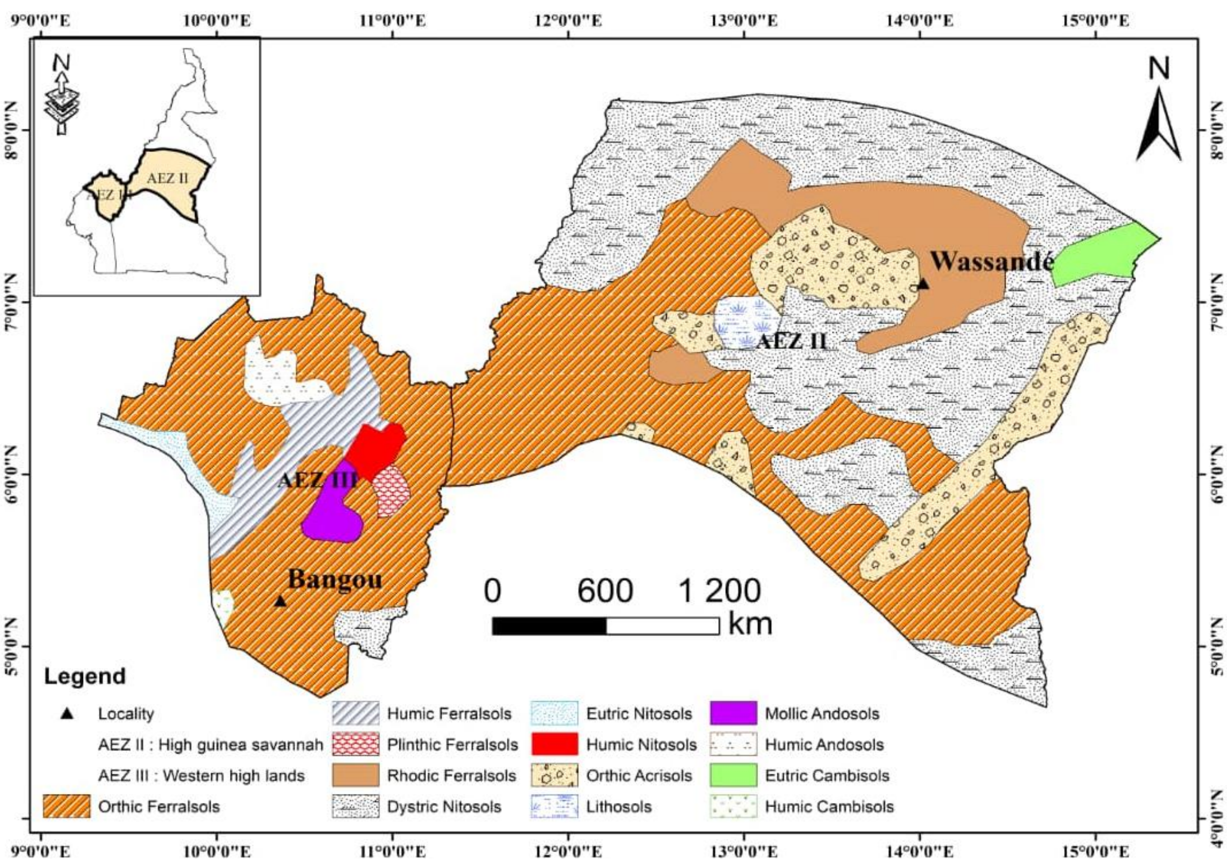

Figure 1. Presentation of the study sites

The experiments were repeated on different plots during the same period in 2022 in order to appreciate the effect of the limestone that occurs in the previous year.

Wassande is a village in the Guinean high savannah agro-ecological zone (AEZ II), located between latitudes 7°03' and 7°32' North and longitudes 13°20' and 13°54' East (Sy et al., 2008). The Guinean high savannah zone is characterised by a humid tropical Sudanian climate, with a monomodal rainfall pattern (Sy et al., 2008). Average rainfall is around 1.500 mm. The average temperature is 22°C. The following soil types are encountered: ferralsols, lithosols, acrisols and cambisols (Ngachie, 1992), ferralsols and acrisols are found in Wassande (Figure 1). Bangou is a village of Western Highlands agro-ecological zone, located between latitudes 4°54'' and 6°36'' North and longitudes 9°18'' and 11°24'' East. The Western Highlands zone is caracterized by a "Cameroonian highland" climate, exhibiting low average temperatures (19°C), with abundant rainfall (1500-2000 mm) following a monomodal pattern. The landscape is characterised by medium-sized mountains, savannah vegetation, depressed basins and plains criss-crossed by gallery forests. The following soil types are encountered: ferralsols, andosols, nitosols and cambisols (Ngachie, 1992), Bangou shows ferralsols (Figure 1).

Plant material

Plant material consisted of healthy potato (*Solanum tuberosum* L.) tubers of similar physiological age provided by the TOWA structure of seed production. Two genotypes Dosa and Jacob2005 were used.

Analysis of the soil physicochemical characteristics

Soil samples were collected at 20 cm depth for analysis before limestone application and 16 weeks after. After being air-dried and crushed, samples were analyzed using the international methods recommended by (Pauwels et al., 1992). For the physicochemical characteristics of the limestone, the pH_{H2O} was 8.1; the cation exchange capacity (CEC) was 40 meq/100g; the Ca content was 22.8 meq/100g; the Al content was 0.00, the Mg content was 6.16 meq/100g and the sum of exchangeable bases (SEB) was 29.26.

General aspects of the field experiments

The experimental fields were cleared, ploughed and ridged. For each experimental site, a field of 2.10 m x 57.5 m was divided into 18 plots of 2.10 m x 2.25 m replicated three times. Limestone was applied 4 weeks before planting (Fageria and Baligar, 2008) at different rates 1, 2, 3, 4 or 5 $t.ha^{-1}$ for each soil fertilization type including unfertilized, NPK-fertilized and NPK+manure-fertilized soils. Non-limed plots of each fertilization type were considered as control plots. Potato seeds were planted in a split-plot design, where soil fertilization type + limestone rate was the plot and potato genotype, the subplot giving a total of 36 experimental units [(3 soil fertilization types) x (5 limestone rates + 1 control) x 2 genotypes] with 3 replicates. Seeds of each potato genotype were planted into each subplot measuring 2.10 m × 2.25 m. Each subplot consisted of 4 rows; spacing were maintained as 75 cm between rows and 30 cm between plants of the same row, giving 8 stems per row and

32 stems per subplot. Each plot and block were separated from each other by a buffer zone of 1.5 m. Fertilization was done at planting time using 405 $kg.ha^{-1}$ NPK (12 6 20) alone or supplemented with 5 $t.ha^{-1}$ chicken manure were applied at and rate (Crum et al., 2005) ; (Sanon and Ouattara, 2019). Plot management consisted of weeding the field, hilling the plants and controlling diseases. Fungicide (Mancozeb 80 wp + Cymoxanil (6 %) + Chlorothalonil (30 %)) was sprayed at one-week intervals at the manufacturer recommended rates, to control late blight. Cypermethrin (360 $g\ l^{-1}$) was sprayed at two-week intervals to control insects.

Data collection and statistical analysis

In each experimental unit, data were collected on 10 plants selected in the center rows following the "W" pattern on 2 yield parameters including the total number of tubers per plant, and the yield of marketable tubers (larger than 30 mm).

Analysis of variance (ANOVA) was used to compare means of the different treatments for each parameter. Means were separated using Fisher's LSD (Low Significant Different) test when the ANOVA test showed significant probability ($p < 0.05$) of difference between means. All analyses were performed using GenStat Edition 12 software (International., 2022).

Results

Data of both first and second seasons were merged as there was no significant difference for season with regard to soil characteristics and yield parameters ($p > 0.05$).

Physico-chemical characteristics of the soil before liming

The quantities of sand, silt and clay contained in the soils are 33%, 35% and 32% in Wassande and 43.5%, 24.5% and 32.0% in Bangou respectively. On the basis of these quantities and according to the USDA (United States Department of Agriculture) textural triangle, soil has a silty-clay texture in Wassande and a sandy-clay texture in Bangou. With a 4.9 pH_{water} (hydrogen potential of water), 3.8 pH_{KCl} (hydrogen potential of potassium chloride) in Wassande and a 5.2 pH_{water}, 4.4 pH_{KCl} in Bangou, these soils are acidic. OM is high in Wassande (3.1 %) and low in Bangou (1.2 %). Nitrogen content is moderate in Wassande (1.33 g/kg) and Bangou (1.54 g/kg); Ca and Mg are low in in Wassande (2.4 meq/100g and 1.8 meq/100g respectively) and higher in Bangou (6.7 meq/100g and 3.60 meq/100g respectively), P content is very low in Wassande (1.7 mg/kg) and low in Bangou (9.7 mg/kg). Aluminium content is high in Wassande (1.4 mg/kg) than in Bangou (0.2 mg/kg), K (potassium) content is low in both sites (between 0.1 and 0.3 meq/100g). Sodium content is moderate in Wassande (0.7 meq/100g) and low in Bangou (0.2 meq/100g). The SEB is moderate in Wassande (5.1) and high in Bangou (10.8) and the CEC is high in Wassande (31.6 meq/100g) and moderate and in Bangou (21.6 meq/100g).

Soil chemical characteristics after liming

Table 1 shows the chemical properties of different soil types as affected by limestone rate in both sites. On unfertilized soil, the pH increased with limestone rate. Higher limestone rates contributed to higher N content. P, Ca and K content increased with the limestone rate, reached a pick at 3 and 4 $t.ha^{-1}$ of limestone in Wassandé and Bangou respectively and started decreasing at higher rates. Na content increased with 1 $t.ha^{-1}$ of limestone and formed a plateau at higher rates. The same trend was observed on fertilized soils for P and Ca content. However, K content reached the pick at 2 and 3 $t.ha^{-1}$ on NPK+manure fertilized soil. Mg increased with limestone rate in both sites, but with higher slopes in Wassande. This trend was observed on fertilized soils. Al content decreased with limestone rate and reached 0.0 at 3 and 5 $t.ha^{-1}$ in Wassandé and Bangou respectively. This same trend was observed on fertilized soils, with slight difference in Bangou where Al content reach 0.0 at 3 $t.ha^{-1}$ on NPK+manure fertilized soil. CEC increased with limestone rate at both sites for all soil fertilization types.

Table 1. Soil chemical properties of the different soil types as affected by limestone rate at both sites

Soil fertilizations types	Parameters	Limestone rate (t/ha) by locality											
		Wassande						Bangou					
		0	1	2	3	4	5	0	1	2	3	4	5
Unfertilized	pH_{water}	4.9	5.7	6.2	6.4	6.6	6.9	5.2	5.5	5.9	6.5	6.5	6.7
	pH_{kcl}	3.8	5.1	5.7	5.8	5.9	6.1	4.4	4.4	4.9	5.1	5.8	6.1
	CO (%)	1.79	2.49	3.38	2.95	2.41	2.41	1.10	2.37	2.54	3.31	3.03	2.76
	MO (%)	3.1	4.3	5.1	5.8	4.2	4.2	1.2	4.1	4.4	4.8	5.2	5.7
	CEC (meq/100g)	31.6	31.2	47	61	68	65	21.6	29.2	30.3	34	46.8	32.8
	N (g/kg)	1.33	1.34	1.36	1.37	1.43	2.45	1.54	1.79	2.10	2.14	2.32	2.52
	P (mg/kg)	1.7	3.1	5.5	10.3	6.3	4.6	9.7	10.9	11.8	13	9.9	9.6
	Al (mg/kg)	1.41	0.1	0.02	0	0	0	0.2	0.19	0.07	0.03	0.01	0
	C/N	14	18	22	18	17	13	7	17	10	13	10	16
	Ca (meq/100g)	2.4	15.4	27.2	28.8	28.5	27.6	6.7	15.7	19	23	25.7	18.2
	Mg (meq/100g)	1.8	4.6	4.9	8	8.1	10	3.6	4.7	5	5	5.5	6
	K (meq/100g)	0.2	0.4	0.4	0.5	0.6	0.5	0.3	0.7	0.7	1.9	3.3	1
	Na (meq/100g)	0.7	0.8	0.9	0.9	0.8	0.8	0.2	1.1	0.9	0.7	1.1	0.7
	SEB	5.1	21.2	33.4	38.2	38	39	10.8	22.2	25.6	30.7	35.6	25.9
NPK fertilized	pH_{water}	4.8	5.4	6.2	6.3	6.6	6.9	4.9	5.4	5.6	6.3	6.6	6.8
	pH_{kcl}	4.1	4.5	5.5	5.6	5.7	5.8	3.9	4.6	4.6	4.7	5.9	6.3
	CO (%)	1.32	1.63	2.33	2.72	2.49	2.17	2.21	2.76	3.26	3.59	3.53	3.31
	MO (%)	2.8	2.3	4	4.7	4.3	3.8	3.8	4.8	5.6	6.2	6.1	5.7
	CEC (meq/100g)	28.2	35	50	54	62.3	67	24	26.4	32	34	42.6	43.6
	N (g/kg)	1.03	1.25	1.32	1.49	1.56	1.71	1.67	1.79	2.00	2.14	2.35	2.95
	P (mg/kg)	7.5	10.3	11.8	12.7	9.8	7.5	13	15.3	15.7	19	18.7	15.1
	Al (mg/kg)	1.3	0.7	0.3	0	0	0	1.5	0.7	0.4	0.05	0.01	0
	C/N	16	11	23	8	19	17	12	12	11	18	21	15
	Ca (meq/100g)	3.4	13.6	25.8	26.2	28.2	26.6	7.1	10.8	16.2	27	27.1	13.8
	Mg (meq/100g)	3.1	3.1	4.2	5.4	7	8.7	4	4	4.9	5	6	7.2
	K (meq/100g)	0.3	0.4	0.5	0.6	0.4	0.4	0.3	1.3	1.4	1.4	1.5	0.8
	Na (meq/100g)	0.2	0.4	0.7	0.9	1	0.9	0.2	0.8	0.9	0.7	0.9	0.6
	SEB	7	17.5	31.1	33.1	36.6	36.6	11.6	16.9	23.4	34.1	35.5	22.4
NPK+ manure fertilized	pH_{water}	5.2	6.2	6.4	6.4	6.5	6.8	4.8	5.6	5.7	6.4	6.6	6.6
	pH_{kcl}	4.6	5.6	5.8	5.9	6.1	6.2	4	4.7	4.7	5.7	5.9	6.1
	CO (%)	1.94	2.25	2.56	3.34	3.18	2.87	2.48	2.98	3.86	3.64	3.92	3.70
	MO (%)	3.4	3.9	4.4	5	5.8	5.5	4.3	5.1	6.7	6.3	6.8	6.4
	CEC (meq/100g)	30	40.7	52	58	62	60.1	29.6	33.6	39	44	49.6	50
	N (g/kg)	1.50	1.62	1.60	1.77	1.78	2.16	1.65	1.96	2.38	2.80	3.00	3.12

P (mg/kg)	16.5	25.3	29.4	43.6	41.2	31.3	17.8	32.1	37.5	41	36.2	34.2
Al (mg/kg)	1	0.4	0.1	0	0	0	0.9	0.3	0.17	0	0	0
C/N	17	21	13	13	20	11	13	13	14	12	13	22
Ca (meq/100g)	5.8	19.4	27.3	27.8	27.4	27.1	10.6	11.3	13	20	26.2	18.6
Mg (meq/100g)	4.6	6.8	8.2	8.5	10.9	11.7	2.6	2.9	3.9	5.3	5.4	8.2
K (meq/100g)	0.5	0.5	0.8	0.8	0.5	0.5	0.5	1.1	1.9	5.2	4.5	4.3
Na (meq/100g)	0.9	0.9	1	1	1.2	1.1	0.8	1	1.1	1.3	1.4	1.2
SEB	11.7	27.6	37.3	38	40	40.4	14.5	16.3	19.9	31.8	37.5	32.3

Legend : pH_{water} , hydrogen potential of water ; pH_{KCl} , hydrogen potential of potassium chloride ; CO , organic carbon ; MO , organic matter ; CEC , cation exchangeable capacity ; N , Nitrogen ; P, Phosphorus ; Al, aluminium , C/N , carbon nitrogen ratio ; Ca , calcium, Mg , magnesium ; K , Potassium, Na , sodium , SEB , sum of exchangeable bases.

Influence of limestone rate on potato yield parameters

The yield parameters evaluated were the number of tubers and the marketable yield. Table 2 shows the mean of square values of potato yield parameters on different soil fertilization types as affected by limestone rate and genotype in Wassande and Bangou. Limestone rates and soil fertilization type affected both yield parameters at both sites. Genotype also influenced marketable yield at both sites. This factor also influenced the number of tubers in Wassande. There was no significant influence of genotype on the number of tubers in Bangou. Interaction between limestone rate and genotypes for all parameters in both sites was not significant. Similarly, there was no interaction between limestone rate and Soil fertilization types for the number of tubers in both sites. However, interaction effect was observed between limestone rate and soil fertilization types for the marketable yield at both sites. Interaction effect was observed between genotypes and soil fertilization types for the marketable yield at Wassandé but not at Bangou**.**

Table 2. Mean squares values of potato yield parameters on different soil fertilization types as affected by limestone rate and genotype in both experimental sites

		Number of tubers		Marketable yield	
Source of variance	Df	Wassande	Bangou	Wassande	Bangou
Limestone rate (L)	5	13.69***	28.16***	137.58***	211.43***
Genotype (G)	1	22.59***	5.07	178***	83.9***
Soil fertilization type (SFT)	2	75.77***	267.01***	3398.64***	8602.93***
LxG	5	1.01	1.88	6.20	5.90
LxSFT	10	0.33	0.99	16.37*	16.46*
GxSFT	2	2.05	4.35	19.06*	10.71

Note :*** : Difference is significant (*p<0.001*) ; * : Difference is significant (*p<0.05*)

Number of tubers

Figure 2 shows the influence of the limestone rate on the number of tubers on different soil types. In Wassande, the number of tubers increased with limestone rate on all fertilization types; itreached higher values (6.80, 8.45 and 9.35 tubers on unfertilized, NPK-fertilized and NPK+manure-fertilized soils respectively) at 4 t.ha^{-1}, and form a plateau at higher rate (Figure 2a).

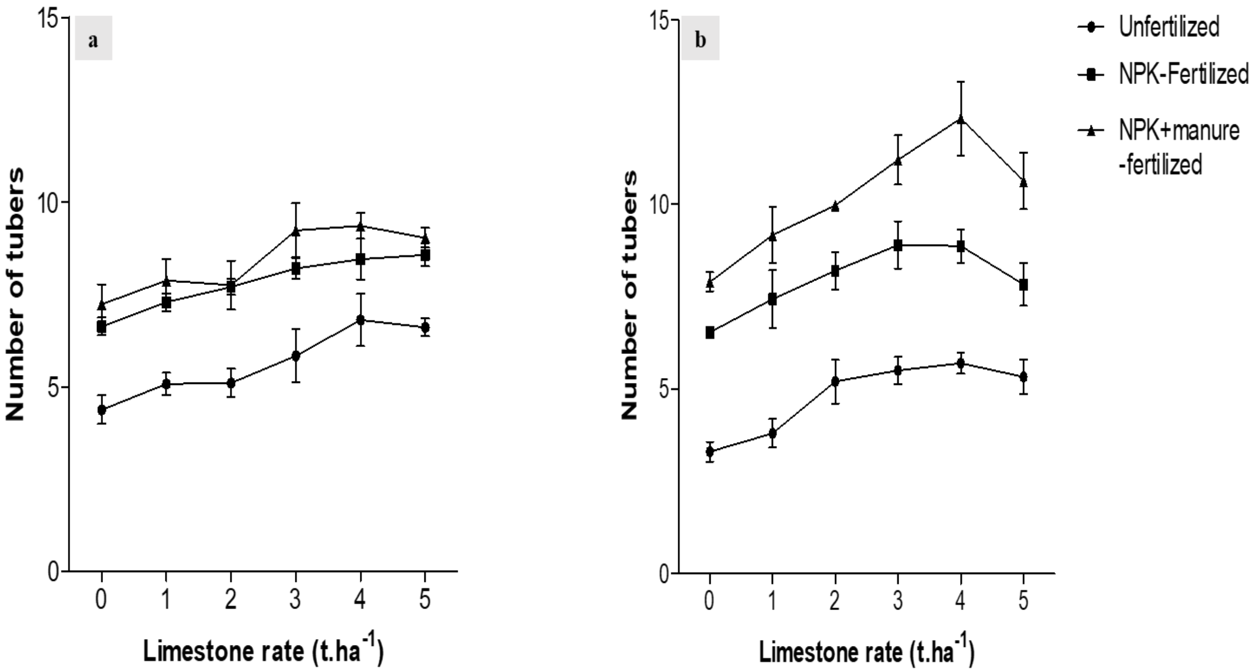

Figure 2. Number of potato tubers per plant as affected by limestone rate on different soil fertilization types in Wassande (a) and Bangou (b)

This parameter also increased in Bangou with limestone rate on all fertilization types and reached a peak (5.70, 8.87 and 12.33 tubers on unfertilized, NPK-fertilized and NPK+manure-fertilized soils respectively) at 4 t.ha^{-1} (Figure 2b). The highest number of tubers was obtained on NPK+manure fertilized soil, followed by NPK-fertilized in both sites.

With regards to the effect of genotype on the number of potato tubers, Dosa produced more tubers (7.71) than Jacob2005 (6.80) in Wassande (Figure 3a). There was no significant difference between both genotypes in Bangou (Figure 3b).

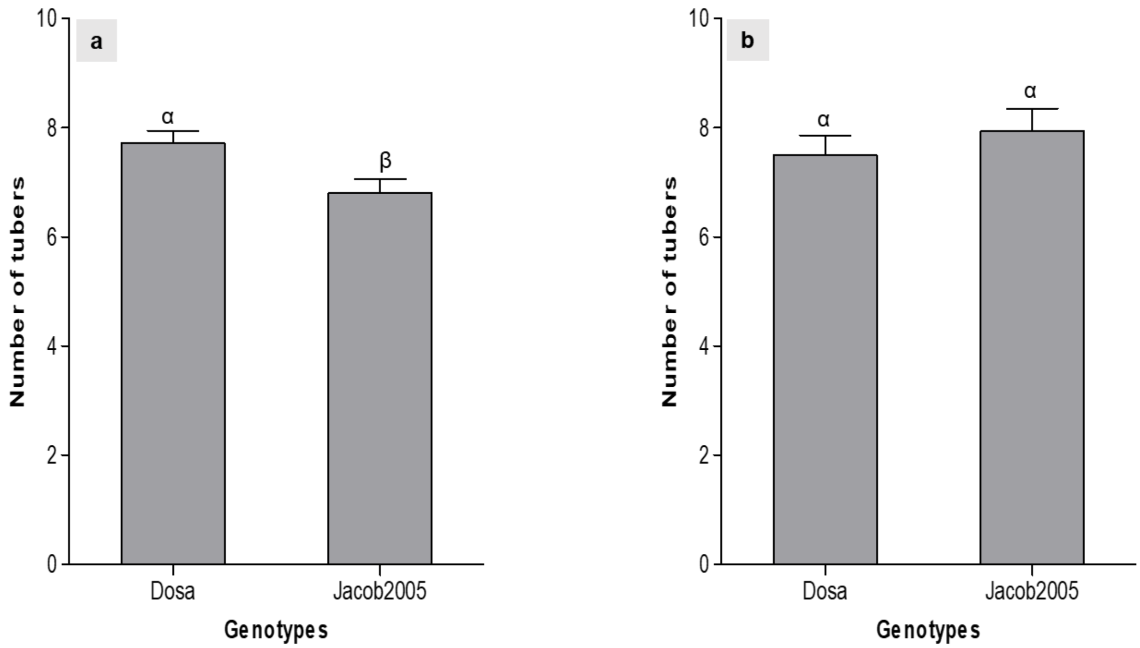

Figure 3. Number of tubers per plant as affected by potato genotypes in Wassande (a) and Bangou (b)

Marketable yield

On unferlized soil, Marketable yield increased with limestone rate and reached the highest values (15.14 and 8.20 $t.ha^{-1}$ in Wassande and Bangou respectively) at 5 $t.ha^{-1}$ of limestone (Figure 4). With regard to fertilized soils, marketable yield increased with limestone rate and reached a peak (28.92 $t.ha^{-1}$ and 31.07 $t.ha^{-1}$ on NPK-fertilized and NPK+manure-fertilized soils respectively) at 3 $t.ha^{-1}$ of limestone in Wassande (Figure 4a). The same trend was observed in Bangou where the peak (29.18 $t.ha^{-1}$ and 41.41 $t.ha^{-1}$ on NPK-fertilized and NPK+manure-fertilized soils respectively) was reached at 4 $t.ha^{-1}$ of limestone (Figure 4b). The highest values of marketable yield were obtained on NPK+manure-fertilized soil, followed by NPK-fertilized in both sites (Figure 4). With regards to the effect of genotype on the marketable yield, Dosa had higher yield (22.37 $t.ha^{-1}$) than Jacob2005 (19.80 $t.ha^{-1}$) in Wassandé (Figure 5a), whereas Jacob had higher yield (22.51 $t.ha^{-1}$) than Dosa (20.74 $t.ha^{-1}$) in Bangou (Figure 5b).

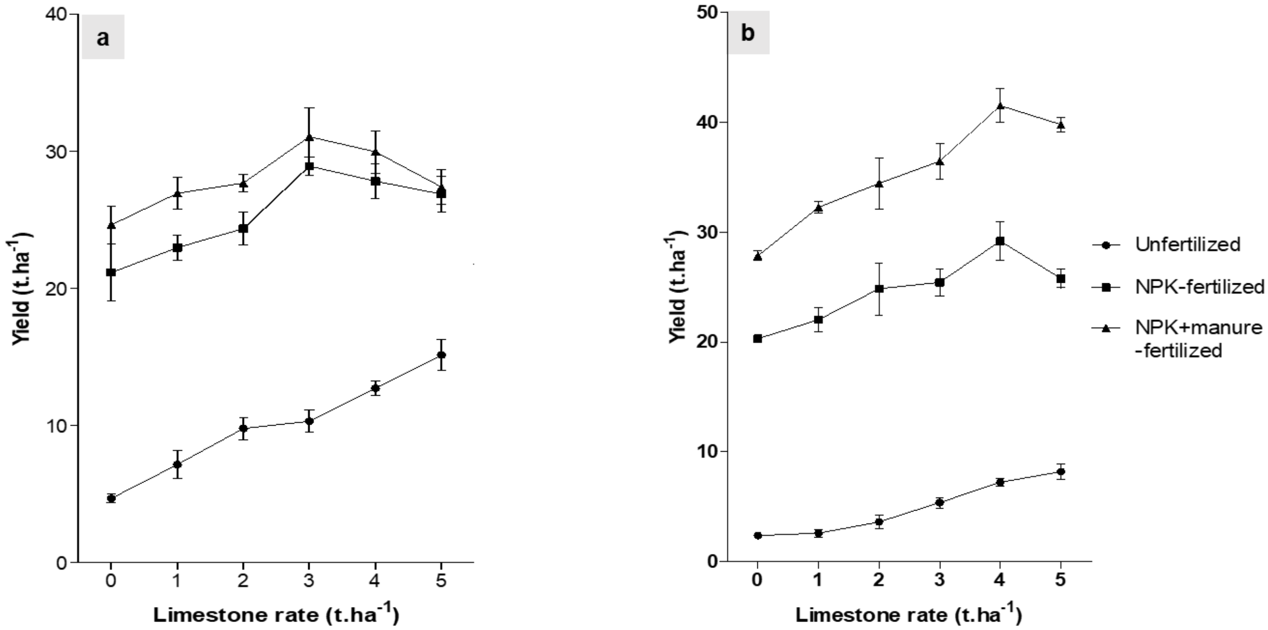

Figure 4. Marketable yield as affected by limestone rate on different soil fertilization types in Wassande (a) and Bangou (b)

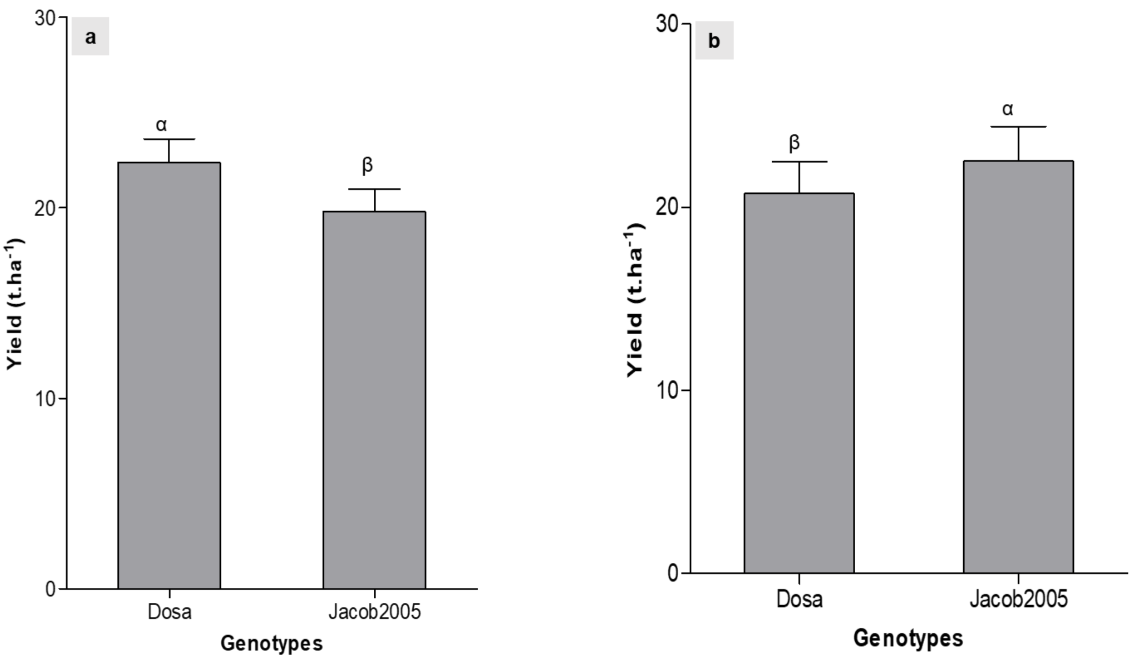

Figure 5. Marketable yield as affected by potato genotypes in Wassande (a) and Bangou (b)

Discussion

Limestone application modified the physico-chemical properties of the soil, whether fertilized or not. Majority of nutrients were higher on fertilized soils than on unfertilized soil. Fertilizer addition increased the availability of some nutrients in the soil as previously reported (Ali et al., 2014). Limestone application significantly increased the pH of the soil, both in terms of pH_{water} and $pH_{KCl.}$ pH_{water} is higher than pH_{KCl} at all limestone rates. Although pHwater is used to determine key soil characteristics, pH_{KCl} is more suitable for estimating exchangeable acidity and knowing the level of exchangeable Al associated with infertility in acidic soils (Antoniadis et al., 2015). Increase in soil pH is due to the release of OH^- ions, and basic cations from calcium carbonate into the soil solution. This release helps to neutralize soil acidity (Antoniadis et al., 2015). The increase in pH with increasing rates of limestone could be explained by the fact that, calcium carbonate has a high pH (8.1). Limestone application contributed to increase organic matter and N in the soil. According to (Grover et al., 2017) increase in soil pH contributes to increase microbial activity, which leads to greater decomposition of OM and consequently increases N content. (Mkhonza, 2020) reported that the large quantities of carbon act as an energy source for microorganisms in mineralization leading to increased N production. In this way, the high levels of OM may have likely contributed to N production through decomposition. Limestone addition increased Ca and P content in the soil. Acidic soils have a high phosphorus fixation capacity due to the high Al and Fe content, hence reducing its availability. The content of P and Ca increased with the limestone rate up to 3 or 4 t/ha respectively and decreased with higher rates. Decrease in Ca and P content may be related to the formation of Ca-P complex which increases with limestone rate as previously reported by (Mkhonza, 2020). Al content decreased with increasing rate of limestone on either fertilized soil or not. According to (Ramaroson, 2017), decrease in the exchangeable Al^{3+} content of soils associated with an increase of calcium carbonate rate is due to the replacement of Al^{3+} ions bound in the colloidal complexes in soil by Ca^{2+} ions. Al content decreased weakly for low limestone rates. On the other hand, a rapid decrease in Al was observed for high limestone rate. The weak reduction in Al^{3+} content could correspond to an exchange phase without neutralization of protons, as reported by (Sanchez and Uehara, 2015). The second phase, linked to the rapid decrease in the Al^{3+} content of soils, could correspond to the neutralization of protons by the OH^- ions provided by the amendments. This may mean that Al^{3+} exchange reactions in the colloidal complexes happens before hydrolysis and proton neutralization (Djondo, 1995).

Changes of soil properties in the present study is associated with improvement potato yield parameters. Results showed that the dose of limestone had a positive influence on the number of potato tubers as compared to the control. This may be due to the increase in P content, which have favored rooting and stolon formation, and consequently tubers formation as previously reported by (Crémer et al., 2008). Yields were better with the combinations of limestone, NPK and manure. This may be due to the fact that the combined application of NPK and manure provides more nutrients to the plant, unlike the application of any of both fertilizers. These results are in agreement with those obtained by (Žydelis et al., 2019) who showed that the combined use of poultry manure and mineral provided better yield in maize as compared to the application of organic or mineral fertilizer alone. Moreover, (Bayu and Gebeyehu, 2013) reported that neither mineral nor organic fertilizers used alone can ensure optimum crop productivity. Integrated use of lime and chemical fertilizers is a good approach for sustainable crop production in acid soils as far as it may build ecologically healthy and sustainable farming systems (Bekele et al., 2018). The high yield obtained on soils with high limestone rate is probably due to the positive effects of liming on soil properties. This results are in agreement with those obtained by (Nduwumuremyi, 2013).The decrease in yield at higher limestone rate may be related to the decrease in many nutrients specially Ca and P which has been reported to be due to the increase of Ca-P complex at higher limestone rates. It has been reported that liming, through optimization of soil pH and improved nutrient availability, improves potato yields under acid soil conditions (Caires et al., 2015). According to Jovovic et al. (2021), increased crop yields due to lime application have been attributed to reduced exchangeable aluminum, increased soil pH and higher concentrations of basic nutrients such as Ca, Mg and K. The addition of lime has also been reported to increase phosphorus uptake, which would otherwise be unavailable to crops due to phosphorus fixation in acidic soils (Ejigu et al., 2023)

Conclusion

This study aimed to determine the optimal limestone rate for sustainable soil management and improved potato production under different fertilization treatments in two agroecological zones of Cameroon. This agro-ecological zones included AEZ II (Wassande) and AEZ III (Bangou). The application of limestone improved the pH and consequently the availability of minerals in the soil at both sites. Increasing concentrations of limestone improved the yields of the two potato varieties studied. The best performance was obtained with 3 $t.ha^{-1}$ of limestone in Wassande which was associated to 5.9 pH and 4 $t.ha^{-1}$ of limestone in Bangou which was associated with 5.9 pH. Policymakers will be able to encourage investment in the processing of agricultural limestone to make it more available to farmers in the various production zones. Dosa had the best performances in Wassande, while Jacob2005 had the best performances in Bangou.

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Author contributions All authors contributed to the study conception and design. Leumassi Mbotchak Michel d'Aquin and Pomo Kamptoum Dieudonné Marcaire collected the field data. Leumassi Mbotchak Michel d'Aquin and Anoumaa Mariette analysed all the data. Leumassi Mbotchak Michel d'Aquin, Anoumaa Mariette and Djomo Sime Hervé conceived the field experiment. The first draft of the manuscript was written by Leumassi Mbotchak Michel d'Aquin and all authors commented on previous drafts of the manuscript. All authors read and approved the final manuscript.

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