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Preliminary Evaluation of Different Combinations of Inorganic and Humate Based Fertilizer on Yield of Potato (*Solanum tuberosum* L.) in Malawi

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Authors' contributions

This work was carried out in collaboration among all authors. Authors KM and ATP designed the study. Authors ATP and OM performed the statistical analysis. Authors ATP, KM and MC wrote the protocol and wrote the first draft of the manuscript. Authors ATP, KM and OM managed the analyses of the study. Authors ATP, WM, FC and OM managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

In Malawi the demand of the use of mineral acidifying fertilizer by farmers for sustenance of high crop yields is increasing. The soaring demand is a pointer to the loss of humic substances in the soil and the resultant poor soil health. There is potential however to reduce the amount of mineral fertilizer used by the farmers and retain the applied nutrients within the plants rooting zone for increased use efficiency and productivity. This could be achieved through the combined application of humate based fertilizers with mineral fertilizer. Therefore, an experiment was conducted to evaluate the effect of different rates of NPK and humate based fertilizer (HBF) combinations on potato yield and yield components at Tsangano, Bembeke and Dwale Extension Planning Area (EPA) in the 2016/2017 cropping season. Ten treatments were laid out in a randomized complete

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block design (RCBD). Baseline soil data were collected and subjected to standard laboratory analytical procedure. Agronomic data collected in the experiment were analyzed in Genstat Discovery Edition 4 and were subjected to analysis of variance (ANOVA) at 95% level of confidence. The means were separated by the least significant difference ($LSD_{0.05}$). Laboratory analysis showed that soils were strongly acid at the three sites with low amount of N, P, K except for Dwale EPA which had high P and medium content of K. Furthermore, results showed that different NPK and HBF combination significantly influenced potato tuber yield and yield components at the three sites. The recommended fertilizer rate of NPK 8:18:15 + 6S at 250 kg ha^{-1} + 60 kg N ha^{-1} produced the highest tuber yield at Tsangano (20,729 kg ha^{-1}) and Bembeke (5,189 kg ha^{-1}). At Dwale EPA, application of NPK 8:18:15 + 6S at 250 kg ha^{-1} produced the highest yield (13,956 kg ha^{-1}). Nevertheless, different combinations of NPK and HBF fertilizer (Treatments 7, 8, 9 and 10) also gave comparably high yields and high number of big tubers. Therefore, the combined application of mineral fertilizer and humate based fertilizer potentially could increase potato yield in Malawi, sustainably. More studies however are required in order to confirm the results.

Keywords: Potato; humate based fertilizer; acidic soils; tuber yield; NPK; climate.

1. INTRODUCTION

Potato is an important food and cash crop in Malawi. Currently, there is great demand for quality potato tubers suitable for different end uses such as crisps, French fries, boiled products and others. Potatoes are efficient in converting natural resources, labour and capital into high quality food. They yield more nutritious food material more quickly on less land than most of the major crops; and the edible food material can be harvested after only 60 days [1]. Despite the increased demand for potato in Malawi, yields and quality of potato tubers obtained by farmers are relatively low. The situation has been attributed to a number of biotic and abiotic stresses. Specifically, [2] identified the following as key constraints: inappropriate fertilizer and soil fertility management, pests and diseases like late blight and bacterial wilt, poor quality seed, use of unimproved seed tubers, and late season drought, exacerbated by the changing climate.

Fertilizer application is essential in potato production for the attainment of optimal quality and yield of tubers. The potato crop has a high nutrient demand due to the prolific development of profuse above ground biomass as well as the production of voluminous tubers below ground per unit area. The crop is a heavy feeder of nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg) and calcium (Ca), in addition to micro elements [3]. Optimal tuber yields of potato are exclusively attainable through the supply of adequate and balanced dosages of nutrients [4]. External supply of nutrients through mineral fertilizer application to the soil for potato production in Malawi is centered on three macronutrients (N, P and K). However, nutrient stocks in the soil and fertilizer application usually do not meet the crop nutrient requirements. Soil acidity and alkalinity complicate potato nutrition in areas where potatoes are cultivated in Malawi. Deficiencies of calcium (Ca), magnesium (Mg) and P are common in acidic soils while boron (B), manganese (Mn) and zinc (Zn) are reported to be deficient under alkaline conditions [5].

Retention in the soil and absorption by plants of major nutrients like N, P and K in the soil is aided by humic substances [6]. Humic substances have a high cation exchange capacity (CEC) and can, as humic acid (HAs), solubilize micronutrients in the soil thereby enhancing the availability of both macro and micro nutrients for uptake by crops [7]. As such presence of sufficient amount of humic substances in the soil can lead to the reduction in the application rate of mineral fertilizer for crop production [6]. With the depletion of humic material in the soil the distorted high input of N, P and K arises [6]. A documented increasing demand of mineral acidifying fertilizer by farmers in the country for sustenance of high crop yields is a pointer to poor soil health. The pattern is indicative of the loss of humic substances in the soil [6]. Potato growers could reduce amount of mineral fertilizer purchase and maintain the applied nutrients within the plants rooting zone through the combined application of humate based fertilizers with mineral fertilizer. It has been reported that the use of either dry or liquid humic materials to soils radically increases crop fertilizer use efficiency [6]. Other workers have reported better uptake of Ca and Mg upon irrigating crops with liquid suspensions of HAs or fulvic acids (FAs) [6]. Candidate humate based fertilizers like Allwin wonder are available that could help address the challenge of declining soil fertility and crop productivity. Allwin wonder, has 18% N, 6% P and 9% K as potassium humate. A study therefore was undertaken to investigate the influence of the application of Allwin wonder on potato yields under Malawian conditions. Specifically the study aimed to determine optimum application rate of Allwin fertilizer for potato production and determine appropriate combination of N, P, K and Allwin fertilizer for potato production.

2. MATERIALS AND METHODS

The study was conducted at Bembeke, Tsangano Sub-Research stations in Dedza and Ntcheu districts respectively of central Malawi, and Dwale Extension planning area (EPA) in Thyolo district, southern Malawi. The potato varieties used were Thandizo variety at Tsangano and Violet at Bembeke and Dwale EPA. Thandizo variety was used at Tsangano due to limited availability of clean planting materials for violet. Gross plot size for individual treatments was four ridges of four meters long while net plot comprised of two inner rows with 32 planting stations. Inter row spacing was 75 cm with an intra row spacing of 25 cm between planting stations. The experiment was laid out in a randomized complete block design replicated 3 times. Pest and diseases were managed through the application of Dithane M45 and Cypermethrin. Dithane M45 was applied fortnightly at the rate of 25 g/16 litres of clean water as preventive control for late blight. Cypermethrin was also applied fortnightly at the rate of 20 ml/16 litres to control pests especially aphids and potato tuber moths.

Treatments: Different combinations of compound N, P, K fertilizer, straight N fertilizer and Allwin fertilizers were evaluated as described below:

1. Control (No mineral fertilizer and Allwin Wonder)
2. NPK 8:18:15 +6S @ 250 kg ha^{-1} + 60 kg N ha^{-1}
3. NPK 8:18:15 + 6S @ 250 kg ha^{-1} + 20 kg N ha^{-1}
4. NPK 8:18:15 + 6S @ 250 kg ha^{-1}
5. Allwin (Wonder) @ 5kg ha^{-1}
6. Allwin (Wonder) @ 2.5 kg ha^{-1}
7. NPK 8:18:15 + 6S @ 250 kg ha^{-1} + 20 kg N ha^{-1} + Allwin (Wonder) @ 5 kg ha^{-1}
8. NPK 8:18:15 + 6S @ 250 kg ha^{-1}+ 20 kg N ha^{-1} + Allwin (Wonder) @ 2.5 kg ha^{-1}
9. NPK 8:18:15 + 6S @ 250 kg ha^{-1} + Allwin (Wonder) @ 5 kg.ha^{-1}
10. NPK 8:18:15 + 6S @ 250 kg ha^{-1} + Allwin (Wonder) @ 2.5 kg.ha^{-1}

Whole quantities of phosphate and potash were applied at planting together with Allwin.

2.1 Data Collection

Data collected included the following datasets; composite soil samples per site, number of plants harvested per plot, number of marketable size tubers, number of non-marketable size tubers, weight of marketable tubers; weight of non-marketable tubers and tuber general appearance (colour, shape, depth of eyes).

2.2 Laboratory and Data Analysis

Laboratory soil analysis was done in order to characterize the soil. Soil samples were analyzed for organic carbon (OC), total N, available P, K, Mg, Ca and soil pH (H_2O). Soil pH was quantified in water (1:2.5) using pH meter [8]. Soil analysis for P, K, Mg and Ca was done by Mehlich 3 extraction procedures [9] while OC was determined using the colorimetric method [10] and total N was determined by Kjeldahl method [11].

3. RESULTS

3.1 Soil Texture and Nutrient Composition

Table 1 summarizes soil texture and nutrient composition for Bembeke, Tsangano, Dwale sites. At Bembeke the soil texture was predominantly clay. Soil pH was very strongly acid (< 4.5) both between 0-20 cm and 20-40 cm. OC was within the medium range (0.88-2.35%) between 0-20 cm and 20-40 cm. Total N content was low (0.08-0.12%) at both levels across the field. Available P was very low (<8.0 mg kg^{-1}) between (0-20 cm) and low (9-18 mg kg^{-1}) between 20-40 cm. K was very low (<0.05 cmol kg^{-1}) at both levels across the field. Ca was low (< 2 cmol kg^{-1}), Mg was very low (<3.0 cmol kg^{-1}) while Zinc was very low (<1.0 mg kg^{-1}). At Tsangano the soil texture was predominantly sand clay loam (SCL). Soil pH was strongly acid (4.5-5.0) both between 0-20 cm and 20-40 cm. OC was within the medium range (0.88-2.35%) between 0-20 cm and 20-40 cm. Total N content was medium (0.12-0.2) to low (0.08-0.12%) at both levels across the field. Available P was very low (< 8.0 mg kg^{-1}) at both levels. K was very low (< 0.05 cmol kg^{-1}) at both levels across the field. Ca was adequate (> 2 cmol kg^{-1}), Mg (<3.0 cmol kg^{-1}) and Zinc were very low (<1.0 mg kg^{-1}) at the site. At Dwale EPA the soil texture was predominantly sand clay (SC) to clay (C). Soil pH was strongly acid (4.5-5.0) both between 0-20 cm and 20-40 cm. OC was within the medium range (0.88-2.35%) between 0-20 cm and 20-40 cm. Total N content was low (0.08-0.12%) at both levels across the field. Available P was very high (> 34.0 mg kg^{-1}) at both levels. K was medium (0.11-0.4 cmol kg^{-1}) at both levels across the field. Ca was high (> 2 cmol kg^{-1}), Mg (<3.0 cmol kg^{-1}) and Zinc were very low (<1.0 mg kg^{-1}) at the site.

3.2 Tuber Yield and Yield Components at Tsangano

Results for tuber yield and yield components for Tsangano are given in Table 2. Fertilizer rates caused significant differences in tuber yield, number of tubers, and number of tubers per plant as well as tuber size. Treatment 2 (recommended fertilizer rate) had the highest tuber yield (20729 kg ha^{-1}). Additionally, Treatment 2 also had the largest tuber size (388.70 g) and highest proportion of marketable tubers (84.00%). Treatments 3, 7, 8 and 10 which had different combination of NPK and Allwin gave comparably high yields that were not significantly different from Treatment 2. Treatment 1, with zero fertilizer, had the lowest yield (7370 kg ha^{-1}) which was also not significantly differently from Treatments 5 and 6 that had only Allwin. Treatments with high yields had corresponding high number of tubers as well as big tubers.

3.3 Tuber Yield and Yield Components at Dwale EPA

There were significant differences in tuber yield, number of tuber, number of tubers per plant and tuber size among the fertilizer rates at Dwale EPA (Table 3; Plate 1). Treatment 4 had the highest yield (13,956 kg ha^{-1}), highest number of tubers per plant (11.74) and largest tuber size (261 g). Tuber yield from Treatments 2, 9 and 10 were not significantly different from each other. Treatments with high yields had corresponding high number of tubers as well as big tubers. However, application of Allwin (Wonder) alone resulted in lower yields (Treatments 5 and 6) than the control treatment.

3.4 Tuber Yield and Yield Components at Bembeke

Table 4 shows results for tuber yield and yield components at Bembeke. Fertilizer rates caused significant differences in tuber yield, number of tubers, and number of tubers per plant as well as tuber size. Treatment 2 (recommended fertilizer rate) had the highest tuber yield (5,189 kg ha^{-1}). Additionally, Treatment 2 had also the largest tuber size (96.90 g) and highest proportion of marketable tubers (20.70%). In terms of yield, Treatment 2 was followed by Treatments 9, 8 and 7 which had different combinations of N, P, K and Allwin (Wonder). Treatment 6, with 2.5 kg ha^{-1} of Allwin (Wonder) produced the lowest yield (2,957 kg ha^{-1}) which was also not significantly differently from the control treatment.

Plate 1. Visible yield differential amongst treatments for Rep 1 at Dwale EPA

Table 1. The soils' physical and chemical properties before the experiment

Site	Depth (cm)	Sand%	Silt %	Clay %	Class	pH	O C %	N %	P mg kg^{-1}	Kcmol kg^{-1}	Cacmol kg^{-1}	Mgcmol kg^{-1}	Zn mg kg^{-1}
Bembeke	0-20	37	18	45	CLAY	4.1	1.44	0.12	1.03	0.03	1.54	0.06	0.07
Bembeke	20-40	30	15	55	CLAY	4.1	1.16	0.10	12.8	0.02	1.33	0.09	0.19
Tsangano	0-20	54	14	32	SCL	4.9	1.95	0.17	0.55	0.04	4.30	0.46	0.18
Tsangano	20-40	53	16	31	SCL	4.7	0.95	0.08	2.08	0.04	3.23	0.28	0.31
Dwale EPA, Thyolo	0-20	43	18	39	SCL	4.9	1.05	0.09	98.4	0.15	3.41	0.54	0.55
Dwale EPA, Thyolo	20-40	51	16	33	CL	4.9	0.96	0.08	107	0.12	3.66	0.43	0.57

Table 2. Tuber yield and yield components for different fertilizer at Tsangano

Treatment	Number of tubers					Weight of tubers (kg/ha)			Tuber Size (g)
	<35 mm	>35 mm	Total	Per plant	Proportion >35 mm	<35 mm	>35 mm	Total	
1	84040	123098	207138	3.88	58.90	1366	6004	7370	138.20
2	53677	279665	333341	6.25	84.00	1185	19544	20729	388.70
3	97483	235290	332773	6.24	70.60	2127	15278	17404	326.30
4	118630	221153	339783	6.37	65.50	1998	12283	14280	267.80
5	103055	164430	267485	5.02	62.70	1549	7976	9525	178.60
6	109425	129172	238596	4.47	54.90	1876	6528	8403	157.60
7	74999	255865	330864	6.20	77.20	1292	16929	18222	341.70
8	125974	220737	346711	6.50	64.00	2182	16345	18528	347.40
9	92322	221333	313656	5.88	68.80	1752	13681	15433	289.40
10	91719	268158	359877	6.75	74.60	1658	19000	20658	387.30
Mean	95132	211890	307023	5.76	68.10	1698	13357	15055	282.30
F Pr	0.303	0.003	0.024	0.024	0.023	0.185	<.001	<.001	<.001
$LSD_{(0.05)}$	55246	77303	88691	1.663	15.13	818	4549	4548	85.28
CV (%)	33.90	21.30	16.80	16.80	12.90	28.10	19.90	17.60	17.60

Notes: 1=Control (No mineral fertilizer and allwin); 2=NPK 8:18:15 + 6S @ 250 kg ha^{-1} + 60 kg N ha^{-1}; 3=NPK 8:18:15 + 6S @ 250 kg ha^{-1} + 20 kg N ha^{-1}; 4=NPK 8:18:15 + 6S @ 250 kg ha^{-1}; 5=Allwin (Wonder) @ 5 kg ha^{-1}; 6=Allwin (Wonder) @ 2.5 kg ha^{-1}; 7=NPK 8:18:15 + 6S @ 250 kg ha^{-1} + 20 kg N ha^{-1} + Allwin (Wonder) @ 5 kg ha^{-1}; 8=NPK 8:18:15 + 6S @ 250 kg ha $^{-1}$ + 20 kg N ha^{-1} + Allwin (Wonder) @ 2.5 kg ha^{-1}; 9=NPK 8:18:15 + 6S @ 250 kg ha^{-1} + Allwin (Wonder) @ 5 kg ha^{-1};10=NPK 8:18:15 + 6S @ 250 kg ha $^{-1}$ + Allwin (Wonder) @ 2.5 kg ha^{-1}

Table 3. Tuber yield and yield components for different fertilizer at Dwale EPA

Treatment	Number of tubers					Weight of tubers (kg/ha)			Tuber size (g)
	<35 mm	>35 mm	Total	Per plant	Proportion >35 mm	<35 mm	>35 mm	Total	
1	262076	89866	351941	6.60	25.50	2982	3127	6109	114.50
2	280821	159449	440271	8.26	35.90	3450	7519	10970	205.70
3	360940	175000	535940	9.48	28.40	3216	6580	9796	183.70
4	385835	240460	626295	11.74	39.00	3418	10538	13956	261.70
5	220311	100444	320756	6.01	31.60	1982	3394	5376	100.80
6	235188	95739	330927	6.20	30.40	2273	3587	5860	109.90
7	253622	154846	408468	7.66	39.20	2509	6586	9095	170.50
8	346694	159152	505846	9.48	31.30	3417	6819	10236	191.90
9	341514	222802	564316	10.58	39.20	2993	8639	11632	218.10
10	267306	228376	495681	9.29	46.20	2223	7886	10109	189.50
Mean	295431	162613	458044	8.53	34.70	2846	6468	9314	174.60
F Pr	0.032	<.001	<.001	0.003	0.017	0.101	0.001	<.001	<.001
$LSD_{(0.05)}$	103939	64385	131484	2.71	10.43	1166	3080	3200	60.00
CV (%)	20.50	23.10	16.70	18.50	17.50	23.90	27.80	20.00	20.00

Notes: 1=Control (No mineral fertilizer and allwin); 2=NPK 8:18:15 + 6S @ 250 kg ha^{-1} + 60 kg N ha^{-1}; 3=NPK 8:18:15 + 6S @ 250 kg ha^{-1} + 20 kg N ha^{-1}; 4=NPK 8:18:15 + 6S @ 250 kg ha^{-1}; 5=Allwin (Wonder) @ 5 kg ha^{-1}; 6=Allwin (Wonder) @ 2.5 kg ha^{-1}; 7=NPK 8:18:15 + 6S @ 250 kg ha^{-1} + 20 kg N ha^{-1} + Allwin (Wonder) @ 5 kg ha^{-1}; 8=NPK 8:18:15 + 6S @ 250 kg ha^{-1} + 20 kg N ha^{-1} + Allwin (Wonder) @ 2.5kg ha^{-1}; 9=NPK 8:18:15 + 6S @ 250 kg ha^{-1} + Allwin (Wonder) @ 5 kg ha^{-1};10=NPK 8:18:15 +6S @ 250 kg ha^{-1} + Allwin (Wonder) @ 2.5 kg ha^{-1}

Table 4. Tuber yield and yield components for different fertilizer at Bembeke

Treatment	Number of tubers					Weight of tubers (kg/ha)			Tuber size (g)
	<35 mm	>35 mm	Total	Per plant	Proportion >35 mm	<35 mm	>35 mm	Total	
1	203682	23172	226854	4.25	10.74	2202	764	2966	55.60
2	263254	69206	332460	7.01	20.70	2861	2308	5169	96.90
3	199625	39093	238717	4.48	16.04	2662	1227	3889	72.90
4	261881	46117	307998	5.77	15.16	2678	1214	3892	73.00
5	216513	48623	265135	5.16	20.54	2039	1217	3256	61.00
6	173739	34660	208399	3.91	16.60	1832	1125	2957	55.50
7	357860	34217	392077	7.25	8.65	3165	1319	4484	84.10
8	319366	34826	354192	6.76	9.68	3481	1389	4871	91.30
9	286055	50943	336998	6.32	15.12	3457	1600	5057	94.80
10	264388	45077	309465	5.80	14.67	3003	680	3683	69.10
Mean	254636	42593	297230	5.67	14.79	2738	1284	4022	75.40
F Pr	<.001	0.005	<.001	<.001	0.003	0.002	<.001	<.001	<.001
$LSD_{(0.05)}$	65242	18312	72053	1.49	5.69	749	487	950	17.82
CV (%)	14.90	25.10	14.10	15.30	22.40	16.00	22.10	13.80	13.80

Notes: 1=Control (No mineral fertilizer and allwin); 2=NPK 8:18:15 + 6S @ 250 kg ha^{-1} + 60 kg N ha^{-1}; 3=NPK 8:18:15 + 6S @ 250 kg ha^{-1} + 20 kg N ha^{-1}; 4=NPK 8:18:15 + 6S @ 250 kg ha^{-1}; 5=Allwin (Wonder) @ 5 kg ha^{-1}; 6=Allwin (Wonder) @ 2.5 kg ha^{-1}; 7=NPK 8:18:15 + 6S @ 250 kg ha^{-1} + 20 kg N ha^{-1} + Allwin (Wonder) @ 5 kg ha^{-1}; 8=NPK 8:18:15 + 6S @ 250 kg ha^{-1} + 20 kg N ha^{-1} + Allwin (Wonder) @ 2.5 kg ha^{-1}; 9=NPK 8:18:15 + 6S @ 250 kg ha^{-1} + Allwin (Wonder) @ 5 kg ha^{-1};10=NPK 8:18:15 + 6S @ 250 kg ha^{-1} + Allwin (Wonder) @ 2.5 kg ha^{-1}

4. DISCUSSION

Generally, the soils at Tsangano, Dwale EPA and Bembeke are strongly acid with low amount of N, P, K and medium content of OC. The strongly acid soils and low level of the nutrients necessitate the external supply of nutrients to increase crop yields. Acidic soils limit crop production by impairing root growth there by reducing nutrient and water uptake [5,12]. These conditions convert available soil nutrients into unavailable form. Furthermore, acidic soils are poor in their basic cations such as Ca, K, Mg and some micronutrients which are essential to crop growth [13]. This is clearly demonstrated in the results whereby, the control treatment (no mineral fertilizer and Allwin) had the least tuber yields across the sites. However, Haile and Boke [12] suggested that the extent of damage posed by soil acidity varies from place to place depending on several factors.

Potatoes have a shallow root system and relatively high demand of most nutrients [14]. Application of fertilizer (NPK, N and Allwin (Wonder) had an influence on potato tuber yield and yield components. Application of recommended fertilizer rate of NPK 8:18:15 + 6S at 250 kg ha^{-1} + 60 kg N ha^{-1} at Tsangano and Bembeke resulted in high tuber yield as well as high number of big sized tubers for varieties Thandizo and violet respectively. Application of NPK 8:18:15 + 6S at 250 kg ha^{-1} at Dwale EPA produced the highest yield using Violet. The differences in genotypic performance over the different sites is striking in this experiment. Genotype-specific differences in nutrient use efficiency have been reported in potato [15,16] and has been attributed to differences in the root system traits and other genetic factors amongst varieties [17,16]. Nevertheless, different combinations of NPK and humate based Allwin (Wonder) fertilizer (Treatments 7, 8, 9 and 10) also gave comparably high yields and high number of big tubers. The comparably high yields could be attributed to enhanced retention in the soil and absorption by plants of major nutrients like N, P and K due to the addition of humic substances through the combined application of mineral fertilizer and Allwin (Wonder). Humic substances contribute to various soil properties (e.g., chelation, buffering, clay mineral-organic interaction, and cation-exchange capacity), which are essential for soil quality [18,19]. Potentially, the soil's cation exchange capacity (CEC) was improved and there was solubilization of micronutrients by humic acid in the soil that led to the enhancement of the availability and uptake of both macro and micro nutrients by the potato [7].

5. CONCLUSION

Under the poor soil fertility conditions and the changing climate, the combined application of mineral and the humate based fertilizer can improve potato production in Malawi, above sole application of humate based fertilizer. The yields are comparable with sole application of mineral fertilizer applied at the recommended rate, even in treatments where Allwin was applied in combination with reduced rates of nitrogen at top dress. Therefore, Allwin and NPK combinations offer promising soil fertility management options for potato production. The increase in potato yield is attributable to enhanced retention in the soil and absorption by plants of major nutrients. Additional crucial mechanism that could have optimized crop fertilizer use efficiency associates to a function of humic materials, which is the amelioration of soil toxicity and reduction of the leaching of N compounds to groundwater. Humic substances bind these major plant nutrients in a molecular form thereby reducing their solubility in water, minimizes leaching and hinders volatilization of N to the atmosphere. Further studies however are required to validate the findings coupled with economic analyses to determine the profitability of the strategy.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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