Dry Matter Accumulation, Nutrient Uptake and Nutrient Use Efficiency of Two Improved Cultivars of Taro (*Colocasia esculenta*) under Screen House Conditions in Samoa

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Author' contributions

This work was carried out as part of PhD research of the first author. The second author provided mentoring and advice on study design. Author SA wrote the protocol, conducted the experiment, wrote the first draft of the manuscript and managed literature searches. Both authors managed the analyses of the study, read and approved the final manuscript.

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ABSTRACT

Taro (*Colocasia esculenta* (L.) Schott) is a staple crop of many of the South Pacific nations with an ever increasing export demand. In recent years, yields of taro have increased dramatically through breeding and selection. However, selections of improved lines are often entirely based on final yield. There are many physiological pathways by which increased potential yield may be achieved. Factors such as the accumulation of dry matter and nutrient use efficiency, merit investigation. Two improved (blight resistant) taro cultivars were planted and harvested for biomass measurements on a monthly basis for a total of eight months (30-240 days after planting) through destructive sampling. At each harvest, plants were separated into various plant parts and their dry matter accumulation and nutrient content were determined. Comparatively, cultivar Samoa 2 showed significantly higher uptake of N (25%), P (37.5%), K (33%), Mg (36.4%), Mn (22.7%) and Zn (48.3%) than cutivar Samoa 1. Even though maximum levels of total plant uptake of nutrients by the two cultivars did not differ between the cultivars, cultivar Samoa 1 plants absorbed 17% less N, 26% less P and 20% less K than those of cultivar Samoa 2 with the uptake uniformly distributed over the entire life cycle of the crop. Although cultivar Samoa 2 resulted in higher total plant (19.6%) and corm dry matter (10.4%) productions, cultivar Samoa 1 had a higher nutrient use efficiency, (kg of edible dry matter produced per kg of nutrient taken up), for N, P, K, Mg, Mn and Cu over cultivar Samoa 2. However, for Ca, Fe and Zn. Cultivar Samoa 2 had a higher nutrient use efficiency over cultivar Samoa 1. Based on nutrient use efficiency of the cultivars, Samoa 1 is recommended for marginal to rich soils while Samoa 2 for good to rich soils.

Keywords: Dry matter accumulation, nutrient uptake, nutrient use efficiency, destructive sampling

1. INTRODUCTION

Root and tuber crops are the major sources of dietary energy for many people in the Pacific island countries. In the Pacific Islands, taro has always been richly woven into the fabric of life [1, 2]. Taro is postulated to have originated in southern or south-east Asia, and to have been dispersed to Oceania through the Island of New Guinea very many centuries ago [1, 2]. The crop has evolved with the cultures of the people of the Asia/Pacific region. Not surprisingly, it has acquired considerable socio-cultural importance for the people. Among the food crops in Oceania region, the adulation and prestige attached to taro is equalled only by yam in certain localities [1-3].

Although the roots are the most widely consumed and important parts of the plant, in the Pacific region, the leaves, petioles and comels of taro are all consumed as fresh vegetables depending on the cultivar and the culture [I,2]. Young taro leaves and stems can be eaten after boiling twice to remove the acrid flavor and the leaves are a good source of vitamins A and C and contain more protein than the corms [4]. Taro corms and cormels are good sources of essential mineral nutrients that contribute to growth as well as health maintenance and general well being [5]. The major mineral nutrient in taro is K [6] and it is also rich in Fe, Zn and Ca [7-8]. Variable mineral nutrient levels between different cultivars of taro were observed in

Papua New Guinea [9]. The corms contained K (250-480 mg/100 g), Mg (19-37 mg/100 g), Ca (11-45 mg/100 g), Zn (0.2-6.3 mg/100 g), Fe (0.6-1.8 mg/100 g) and Na (0-3 mg/100 g). Taro is a good source of Na , K, Mg and Ca whose salts regulate the acid-base balance of the body [10]. Wide variations observed among different cultivars of taro have been attributed to differences in genetic background as well as climate, soil, season and agronomic factors [10,11].

Variation in mineral composition among the accessions of taro is probably due to differences in the genetic potential of each accession to obtain nutrients from the soil since different taro genotypes have different nutrient-use efficiencies [12,13]. As was found in the present study, regarding mineral content, high levels of variability in South East Asia and Oceania taro germplasm were also found with regards to chemical composition for minerals but also for lipids, proteins, amylose, glucose, fructose and saccharose [11-14]. Availability of N, P, K and S fertilizers increase yield as well as nutritional quality of root and tuber crops [15].

In most studies with food crops in the Pacific, biomass production and nutrient uptake receive little attention, particularly due to the tedious and difficult nature of the quantification process [11]. This has led to a scarcity of basic information regarding dry matter accumulation and nutrient uptake for the taro crop, particularly under intensive cropping systems which are aimed at satisfying the crop demand of a growing population and supplying corms for export markets. An essential step to increase the efficiency of fertilizers in order to improve yields is an understanding of nutrient uptake and allocation within the taro plant during the growing season [13]. These data are essential for the development of technological packages, especially involving nutrient inputs, growth simulation models, and decision support system [13]. This information is also critical for the establishment of taro breeding programs aimed at raising the yield potential of taro [2].

The objective of this research was to investigate the dry matter accumulation, nutrient uptake and nutrient use efficiency of two improved taro cultivars, *Samoa 1* and *Samoa 2*, grown under semi-controlled screen house environment, through regular temporal destructive sampling. These two new cultivars were bred locally for resistance to taro leaf blight and have adapted well to the local growing conditions. In addition, these two cultivars have excellent taste characteristics over other newly bred lines and have been successfully accepted in the local market and have been endorsed for the export markets as well as for value addition. Therefore, it is imperative to ascertain the nutrient uptake data which reflects on the nutritional value data for these two new local cultivars in order to realize their full economic potential.

2. MATERIALS AND METHODS

2.1 Study Area

This experiment was conducted at the University of the South Pacific's Alafua Campus in Samoa (15-17^o S and 171-173^o W). The location experiences a humid tropical climate with an annual rainfall varying from 2,500 to 3,500 mm with a strong seasonality of distribution. The months from April to October are the driest times of the year. The average annual air temperature range is 20–33^{o}C [3].

2.2 Soil Characterization

The soil used was a well-drained inceptisol, oxic humitropept, clayey-skeletal oxidic isohyperthermic. The initial chemical characterization of the soil is given in Table 1 below. The soil was air dried and sieved through a 1 cm mesh. The potting bags were filled with 10 kg of soil each.

Table 1. Chemical characterization of the trial soil.

Chemical and nutritional composition	
pH (H_2O)	6.0
CEC (cmol$_c$/kg)	20.83
EC (dS/m)	0.22
OC (%)	3.2
Total N (%)	0.43
Olsen P (mg/kg)	3.85
Exchangeable K (cmol$_c$/kg)	0.32
Exchangeable Ca (cmol$_c$/kg)	9.74
Exchangeable Mg (cmol$_c$/kg)	1.07
DTPA Extractable Fe (mg/kg)	38.97
DTPA Extractable Mn (mg/kg)	49.46
DTPA Extractable Cu (mg/kg)	3.45
DTPA Extractable Zn (mg/kg)	2.86

2.3 Nutrient supplementation and incubation

The entire package of macro and micronutrient elements, based on the soil pH, was included for nutrient supplementation to each pot, carried out at recommended levels as described by Asher et. al, (Table 2) [16]. An incubation time of two weeks was allowed before the planting of the two taro cultivars.

Table 2 Typical rates of nutrient supplementation for soils with a pH of 6.0.

Element	Application Rates (kg/ha)
N	100
P	60
K	80
Ca	35
Mg	30
Fe	5
Mn	5
Cu	3
Zn	4

(Source: [16])

2.4 Plant culture and experimental layout

Suckers of two improved taro cultivars, *Samoa 1* and *Samoa 2*, were planted in pots and laid out in a factorial arrangement, using randomised complete block design with five replications. Each replication consisted of plots randomly assigned to the two cultivars which were to accommodate eight randomly assigned monthly biomass harvests, sampled for dry matter accumulation and nutrient uptake at different stages of plant growth. There were six data plants of each variety from each block for each of the eight harvests totaling to 240 plants for each cultivar (480 plants for the whole experiment). The cultivars and harvest periods were completely randomized within a block.

2.5 Data collection

Six taro plants of each cultivar from a block were harvested at 30, 60, 90, 120, 150, 180, 210, and 240 days after planting (DAP), to ascertain the dry matter measurements and total chemical analysis of individual plant parts. Plants in the sub-plots were harvested, washed and separated into petioles, corms, roots and sucker components. Samples of the various plant parts were oven dried to a constant weight at 65^{o}C for dry matter determination. The dried samples were ground to pass through a 1.0-mesh screen and analysed for total N, P, K, Ca, Mg, Fe, Mn, Cu and Zn. The third most upper leaf laminar was also analysed for these elements at 30, 60, 90, 120, 150, 180, 210, and 240 days after planting (DAP). Nitrogen was determined by the micro-Kjeldahl procedure [17], P by molybdovanadophosphoric acid [17], and K, Ca, Mg, Zn, Fe, Mn, and Cu by atomic absorption spectrophotometry [18,19].

2.6 Nutrient uptake calculations

Nutrient uptake and accumulation were calculated as the product of dry matter content and tissue nutrient concentrations for the various plant parts at various stages of growth over the entire growth cycle of the crop. The mean values from the six data plants, for each nutritional index and the number of plants per hectare were used to extrapolate nutrient uptake on a hectare basis. The nutrient use efficiency was calculated as the kg of corm dry matter produced per kg of nutrient taken up [13,14].

2.7 Statistical analysis

All the data collected were subjected to two-way analysis of variance. Best-fit curves were determined using polynomial regression procedures of the Genstat Statistical Software package [20]. Only coefficients significant at $P < 0.05$ were retained in the model.

3. RESULTS AND DISCUSSION

3.1 Results

<u>3.1.1 Dry matter accumulation by various plant organs</u>

The accumulation of dry matter by various plant organs of the two cultivars is illustrated in Figure 1a-f. The mean total dry matter yield showed cultivar Samoa 2 had 19.6% higher accumulation than cultivar Samoa 1 throughout the experimental period (Table 4). The first 90 days after planting (DAP) were characterized by low rates of total dry matter production by both the cultivars (Figure 1a), however, statistically significant with cultivar Samoa 2 accumulating higher dry matter yield. During this period, leaves and petioles accounted for 58% of the total dry matter produced in each cultivar (Figure 1a-c). Following 210 DAP, the dry matter content in the leaves and petioles declined to less than 25% of the total dry matter, but it increased significantly in corms and suckers (Figure 1e and f). During the first 90 DAP, roots of cultivars Samoa 1 and Samoa 2 represented about 13% and 18% of the total dry matter content, respectively. Following 180 DAP, the dry matter content in the roots was never higher than 8% for Samoa 1 and 12% for Samoa 2. Cultivar Samoa 2 accumulated significantly higher root dry matter than Samoa 1 throughout the experimental period. It is noteworthy that, between 150 and 240 DAP, the suckers were a significant sink of dry matter in the taro plant. During this period, these organs accounted for 22% of the total plant dry matter in

Samoa 1 and 13% in Samoa 2. Maximum significant dry matter accumulation in the corms of both cultivars was recorded between 210 and 240 DAP, accounting for about 46% of the total plant dry matter.

3.1.2 Nutrient uptake of the two taro cultivars

Two way analysis of variance revealed significantly higher uptake of N (25%), P (37.5%), K (33%), Mg (36.4%), Mn (22.7%) and Zn (48.3%) by cutivar Samoa 2. (Table 4). In general, the nutrient uptake was very similar between cultivars during the first 150 DAP; thereafter, the quantity of all the nutrients taken up by plants of cultivar Samoa 1 was lower than that of cultivar Samoa 2. The only exception was for Fe uptake where uptake by cultivar Samoa 1 was higher than culticar Samoa 2, however, this was not significant (Figure 2a-e and Figure 3 a-d, Table 3).

3.1.3 Maximum levels of total plant uptake of nutrients by the two cultivars (kg/ha)

There were no statistical difference between the two cultivars for the maximum levels of total plant uptake of nutrients (Table 4). However, it is noteworthy that cultivar Samoa 1 plants absorbed 17% less N, 26% less P and 20% less K than those of cultivar Samoa 2 with the uptake uniformly distributed over the entire life cycle of the crop. These results also suggests that, as with most root crops, taro has a high requirement for K relative to N (Table 4).

3.1.4 Leaf nutrient concentrations

The nutritional analyses of the third uppermost leaf laminar of the two cultivars revealed only significantly higher concentrations of Mg (12.5%) and Zn (22.2%) in cultivar Samoa 2. In general, the concentrations of all the nutrients except Fe in the leaf laminar of cultivar Samoa 1 plants had greater concentrations than cultivar Samoa 2 plants though not statiscally significant (Table 5).

3.1.5 Nutrient use efficiencies

There were significant differences in the total and corm dry matter productions between the cultivars throughout their entire growth period (Table 4). Cultivar Samoa 1 had a higher nutrient use efficiency (kg of edible dry matter produced per kg of nutrient taken up), for N, P, K, Mg, Mn and Cu over cultivar Samoa 2. However, for Ca, Fe and Zn, cultivar Samoa 2 had a higher nutrient use efficiency over cultivar Samoa 1 (Figure 4 and Figure 5). In another separate field trial, the effect of the taro genotype was significant for more than half of the analysed minerals (i.e., Mg, Ca, Zn, Fe, Mn) [22].

3.2 Discussion

Taro exhibits continuous partitioning (a balance between vegetative growth and storage organ growth is maintained throughout the growing) with an almost linear increase in fresh and dry weights [25,26]. The dynamics of dry matter accumulation, nutrient uptake and partitioning by two taro cultivars with fertilization under natural open field conditions showed similar patterns from a research carried out in Isabella, Puerto Rico [13]. In a separate investigation involving comparisons between natural field conditions and 50% shade conditions, the corm yields were not affected by shade but the total biomass increased under shade as opposed to full sunlight [29]. Corm percentage dry matter, which reflects quality, was also reported to be higher under shade. These were attributed to greater photosynthetic efficiency resulting from increased stomatal and chlorophyll densities as aroids are shade tolerant crops [25,29].

The findings of this study showed that the dry matter accumulation by various plant organs followed analogous sigmoid patterns over the crop life cycle as reported by other authors [13,14,29,30]. Towards senescence, the suckers were the principal sink of dry matter for both the cultivars. This result is of particular importance because, when taro is grown under upland conditions, cormels of suckers seldom reach a marketable size; and they may compete for assimilates with the marketable main corm. This finding may influence such decisions as to remove the competing suckers at later stages of crop growth [12].

The comparatively higher nutrient uptake of cultivar Samoa 2 can be ascribed to the genotypic variations as reported by various other researchers who worked with taro [14, 27-30]. Other studies on the N, P and K content of different plant parts at various growth stages revealed that the nutrient content changes with increase in age of the crop. The N and K contents in the foliage of taro were reported to be at its highest after 150 DAP; thereafter, decreased with maturity. The N content of root, tuber and pseudo-stem decreased towards maturity of the crop [13,14, 30]. This was in agreement with the findings of this study with days after planting highly significant across all the nutrients analysed..

Both cultivars exhibited higher levels of K uptake relative to N. Analogous findings were reported with the total plant as well as corm being characterised by

Table 3 Mean dry matter yield (kg/ha) and plant uptake (kg/ha) of nutrients by the two cultivars various across the 8 monthly biomass harvests.

Cultivar	Mean (kg/ha)									
	Total dry matter**	N**	P***	K***	Ca	Mg****	Fe	Mn	Cu	Zn***
Samoa 1	664	78.7	13.6	123.6	47.3	10.7	5.6	0.43	0.040	0.178
Samoa 2	809	98.4	18.7	164.4	55.4	14.6	4.7	0.53	0.047	0.264
LSD (5%)	106.3	13.30	2.13	24.36	11.12	1.71	1.5	0.09	0.010	0.031

*, **, *** Significant at 0.05, 0.01 and 0.001 probability levels, respectively.

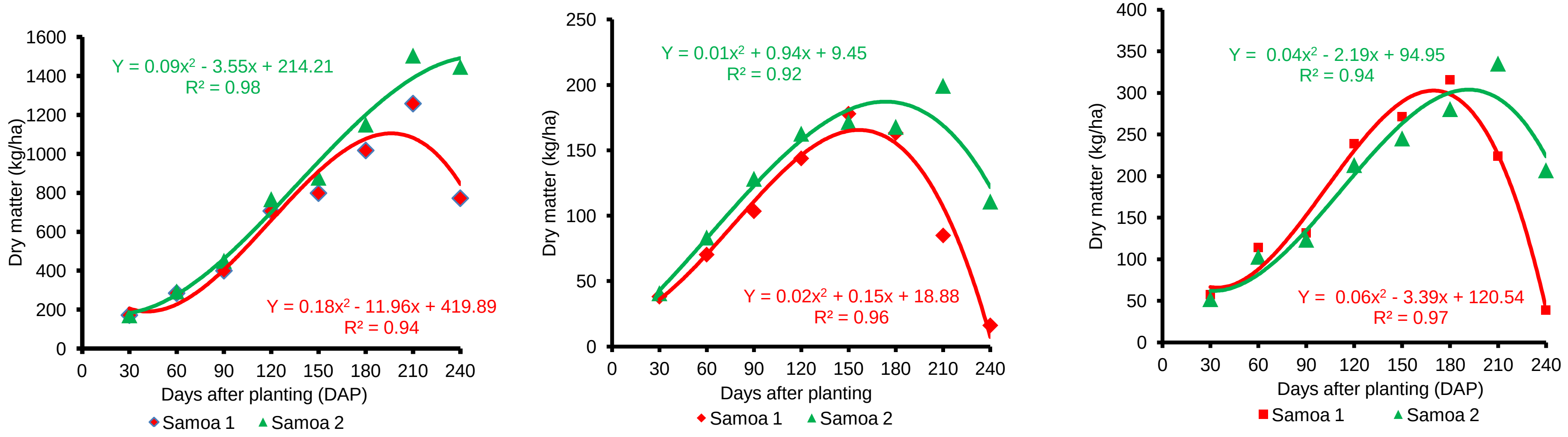
Table 4 Maximum levels of nutrient uptake by the two cultivars (kg/ha)

Nutrient	Samoa 1	Samoa 2	P (0.05)	LSD (5%)
N	146	176	0.310	62.11
P	35	47	0.051	12.06
K	259	321	0.257	111.35
Ca	165	183	0.477	40.88
Mg	20	28	0.087	9.02
Fe	21	15	0.156	7.80
Mn	0.9	1.1	0.237	0.39
Cu	0.07	0.08	0.102	0.39
Zn	0.39	0.54	0.095	0.175

Nutrient concentration of the two taro cultivars

Table 5 Percent nutrient concentration in the lamina of the third uppermost leaf of the two taro cultivars at various stages of growth.

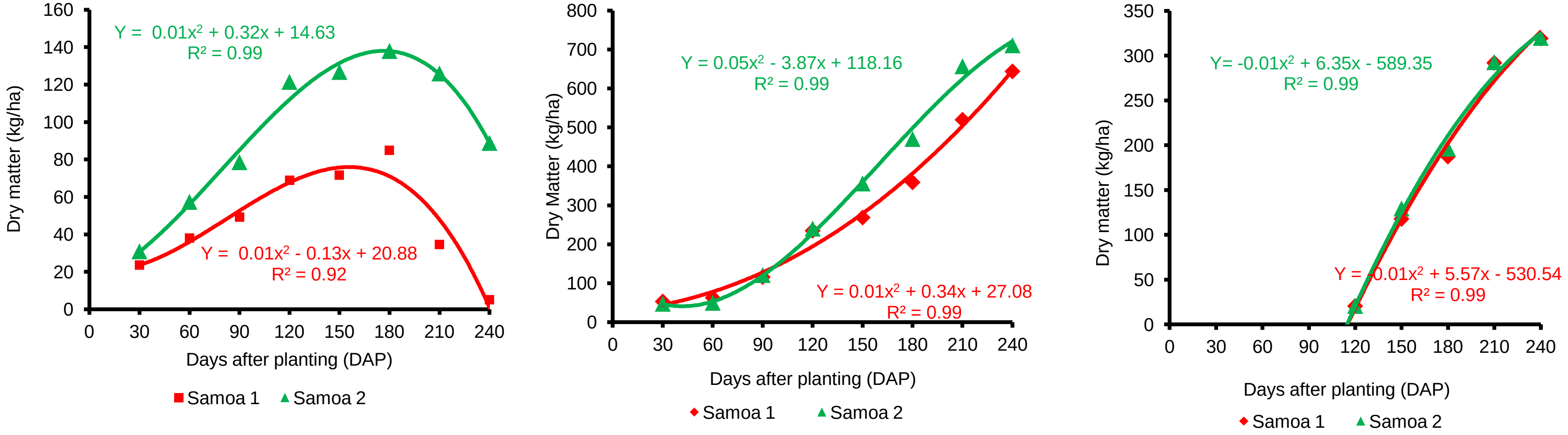
Days after planting (DAP)	Cultivar (CV)	Nutrient Content (%)								
		N	P	K	Ca	Mg	Fe	Mn	Cu	Zn
30	Samoa 1	4.73	0.33	3.85	0.97	0.18	0.104	0.068	0.003	0.014
	Samoa 2	4.87	0.34	2.87	0.78	0.30	0.120	0.060	0.004	0.019
60	Samoa 1	4.21	0.44	3.33	1.82	0.16	0.425	0.059	0.005	0.017
	Samoa 2	4.39	0.46	3.11	1.54	0.18	0.489	0.075	0.005	0.028
90	Samoa 1	3.89	0.41	2.93	2.30	0.37	0.625	0.049	0.006	0.028
	Samoa 2	4.01	0.44	2.89	2.21	0.45	0.513	0.050	0.007	0.036
120	Samoa 1	4.37	0.41	3.75	2.23	0.37	0.675	0.053	0.010	0.024
	Samoa 2	4.53	0.43	3.71	1.76	0.37	0.733	0.045	0.011	0.040
150	Samoa 1	3.94	0.41	4.01	1.42	0.35	1.052	0.069	0.007	0.031
	Samoa 2	4.29	0.39	4.00	1.17	0.29	0.940	0.067	0.007	0.036
180	Samoa 1	2.94	0.39	3.78	12.11	0.31	1.103	0.085	0.006	0.033
	Samoa 2	3.43	0.38	3.63	10.82	0.31	1.364	0.090	0.006	0.036
210	Samoa 1	3.14	0.47	3.35	2.40	0.27	1.649	0.071	0.006	0.031
	Samoa 2	3.18	0.40	3.35	1.97	0.29	0.645	0.074	0.005	0.036
240	Samoa 1	4.18	0.56	3.34	1.95	0.36	0.575	0.066	0.006	0.029
	Samoa 2	3.41	0.48	2.91	2.41	0.34	0.050	0.064	0.005	0.038
P-value (5%)	CV	0.440	0.417	0.067	0.751	0.016	0.154	0.595	0.958	<0.001
	DAP	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	CV x DAP	0.637	0.125	0.626	0.015	0.002	0.028	0.336	0.994	0.071
LSD (5%)	CV	0.271	0.023	0.205	0.463	0.1003	0.1067	0.0058	0.0010	0.0019
	DAP	0.543	0.045	0.411	0.926	0.2005	0.2134	0.0116	0.0019	0.0038
	CV x DAP	0.767	0.064	0.581	1.310	0.2836	0.3018	0.0164	0.0027	0.0053



(a) Total

(b) Leaves

(c) Petiole

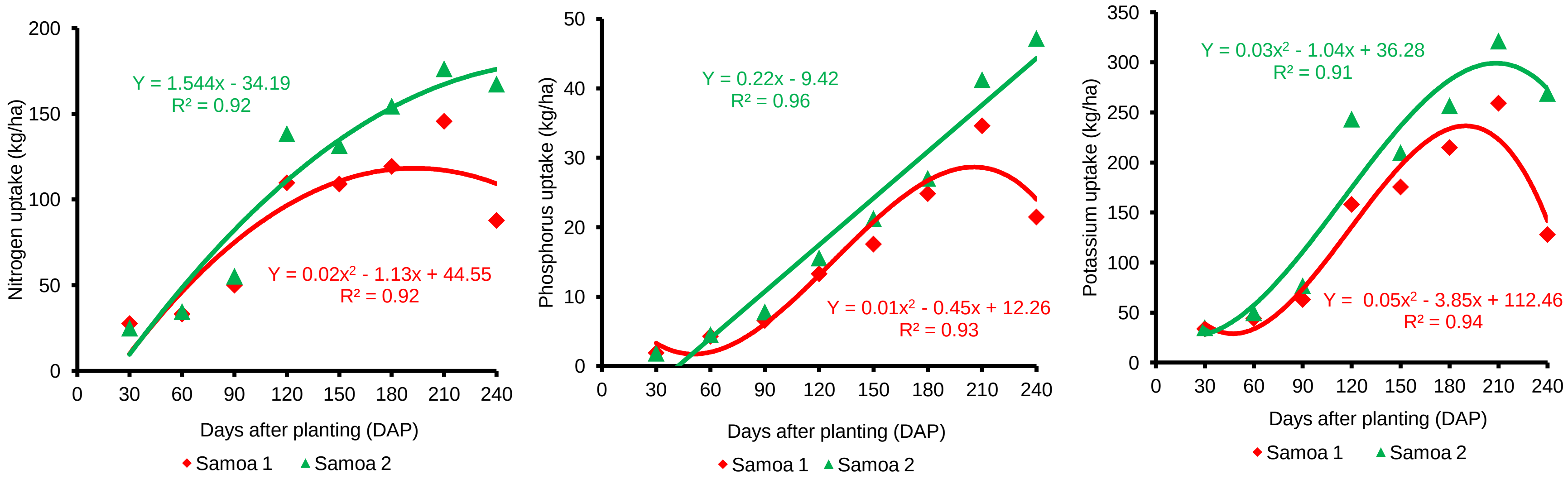


(d) Roots

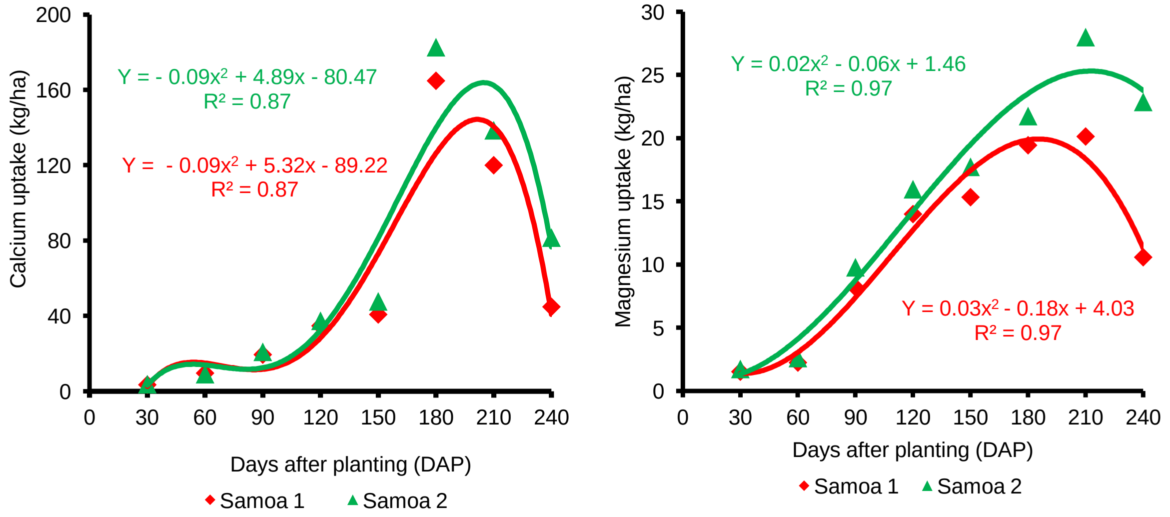
(e) Corms

(f) Suckers

Figure 1 Dry weights of plant organs of the two taro cultivars as influenced by age

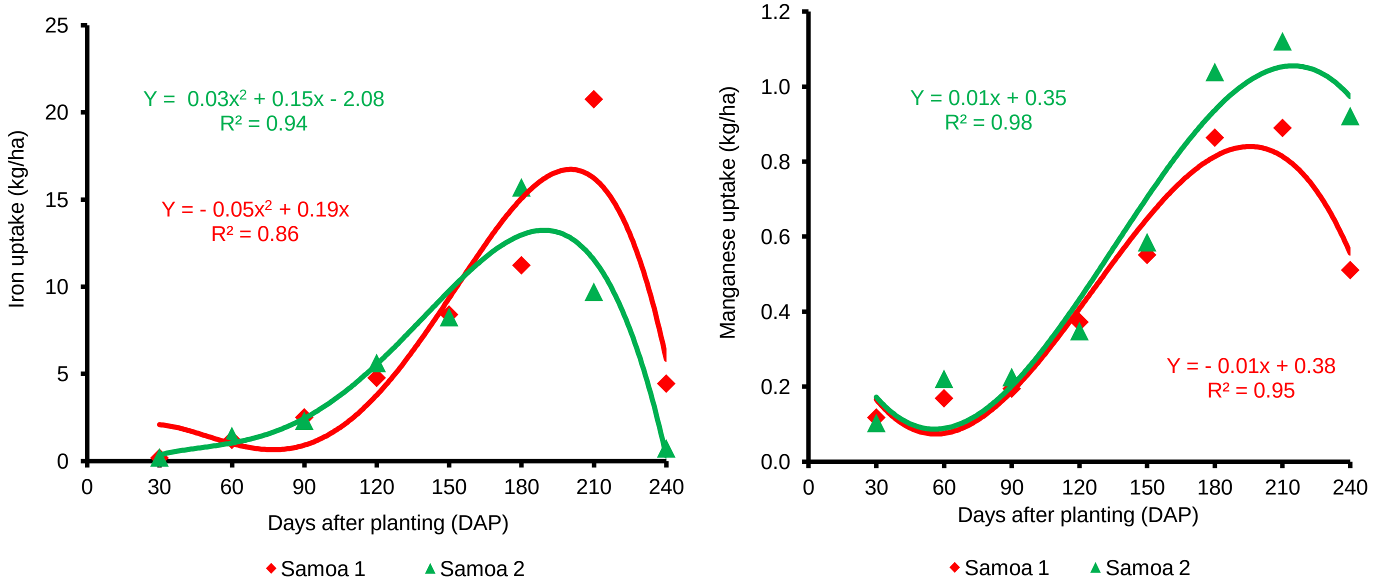


(a) Nitrogen (b) Phosphorus (c) Potassium



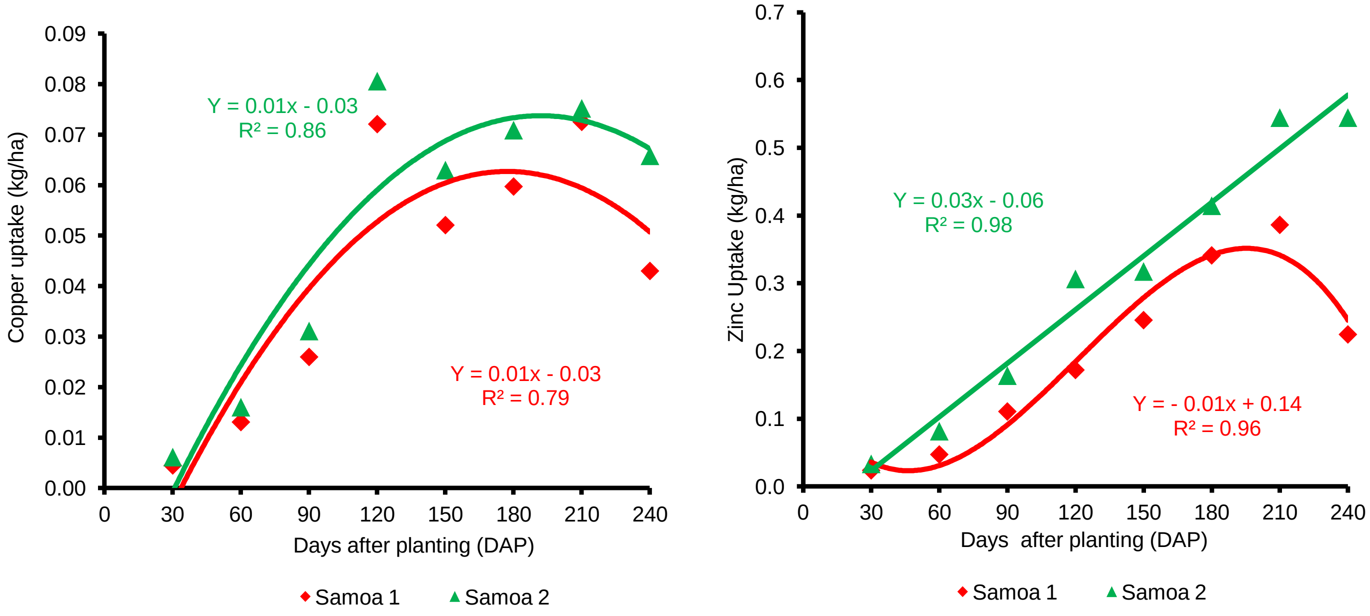
(d) Calcium (e) Magnesium

Figure 2 Macronutrient contents of the two taro cultivars as influenced by plant age



(a) Iron

(b) Manganese



(c) Copper

(d) Zinc

Figure 3 Micronutrient contents of the two taro cultivars as influenced by plant age

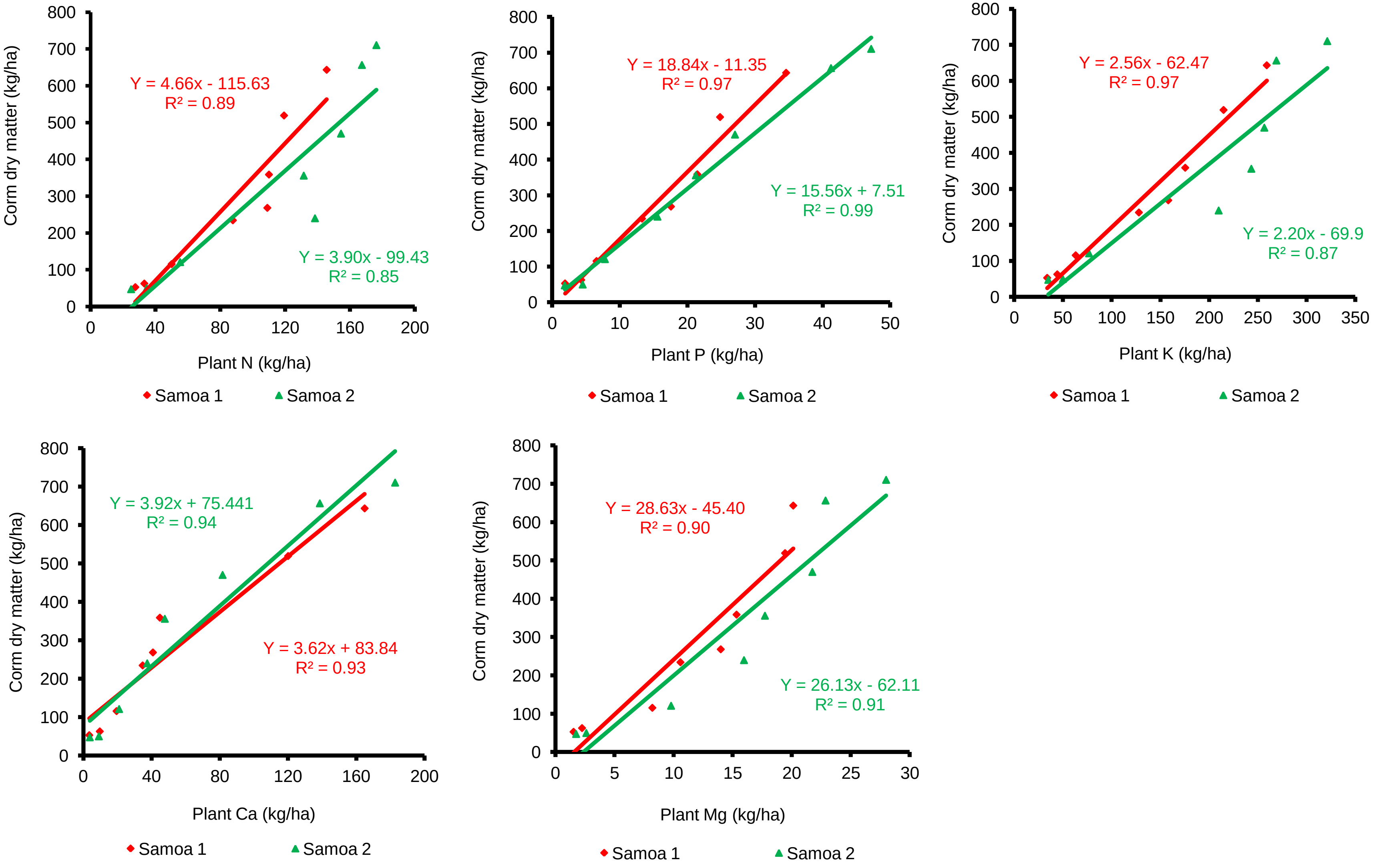


Figure 4 Relationship between corm dry matter yield and macronutrient contents of the two cultivars

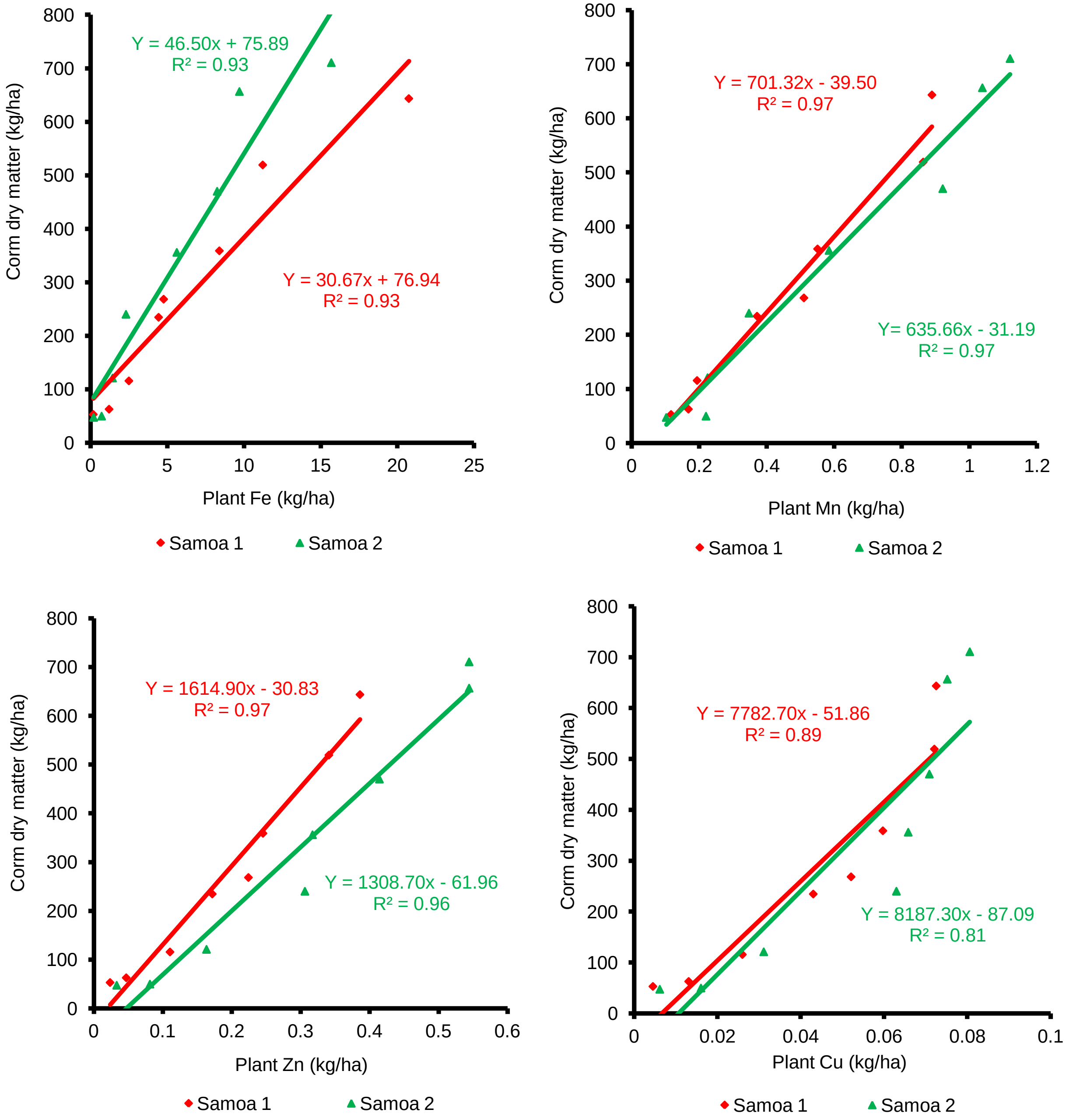


Figure 5 Relationship between corm dry matter yield and micronutrient contents of the two cultivars

high concentrations of K [22]. Poassium application resulted in greater leaf area and leaf area duration and exerted a profound influence in diverting greater proportion of dry matter into corms than N and increased the dry matter accumulation in corms, corm size, and yield. The increase in corm yield due to K was attributed partly to its effect in bringing about slightly earlier corm initiation and partly to an increase in bulking rate [30].

The variations in the leaf tissue nutrient concentrations can be attributed to genetic differences between the cultivars [23]. Higher plant vigour and sucker production was observed by cultivar Samoa 2 relative to cultivar Samoa 1 [24]. Among the different plant portions, leaf was found to be the the richest in N (4-5%). Parallel findings were reported by other researcher. [9,27-30]. This is of high nutritional significance, since leaves are consumed as fresh vegetable in the Pacific island communities.

Furthermore, the nutrient use efficiencies, computed as the weight of edible dry matter produced for every kg of nutrient taken up, revealed that though cultivar Samoa 2 had higher nutrient uptake, it required greater quantities of N, P, K, Mg, Mn and Cu to produce one kg of dry matter as compared to cultivar Samoa 1. Conversely, Ca, Fe and Zn were required in relatively higher amounts by cultivar Samoa 1 as oppsed to cultivar Samoa 2, to produce one unit of corm dry matter. Efficiency ratios can be influenced by the duration of the crop, fertilisation, amount of solar radiation and drought [14]. Therefore, comparison of ratios among species or cultivars and across environments or management packages should be conducted with caution [29,30]. In this experiment, the cultivars were grown under identical conditions; however, future expeimentation using a more limited nutrient supply would confirm the superior nutrient efficiency of cultivars under field conditions.

CONCLUSIONS

There has been limited number of experiments in the Pacific characterising the inter-relationship between growth, development and nutrient uptake of the taro crop. However, as the demand for taro increases in the local, processing and export markets, the required volume will only be met through extensive plantings using modern management packages.
Implementation of such technological packages will require readdressing the current cultural and management practices and basic research to achieve higher yields.

The results of this study exhibited the inherent cultivar differences in relation to patterns of dry matter accumulation in various components of the taro plant.

The results of this study also revealed that both of the locally bred taro cultivars from Samoa are capable of absorbing a wide range of minerals with relevance to human dietary allowances and health. A complete information package on the nutritional composition of local taro germplasm would help to guide policy makers, nutritionist and researchers in incorporating the crop cultivars into the various diversification programs.

This investigation revealed that overall cultivar Samoa 1 had had a relatively better nutrient use efficiency than cultivar Samoa 2. On the basis of this finding, Samoa 1 is better adapted for marginal to rich soils while Samoa 2 for moderate to rich soils.

Results from this investigation can be valuable for breeding programs dealing improvements in taro nutrient use efficiency as well as nutritional composition.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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