Effects of Mulching/Green Manuring and Intercropping With *Crotalaria grahamiana* on Growth and Yield Parameters of Potato in the Vakinankaratra Region, Madagascar

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Abstract:

Potato (*Solanum tuberosum*) is an important food crop and income source for rural households in the Highlands of Madagascar, especially in the Vakinankaratra region, the main production area. The present field study aimed to evaluate, under two growing seasons, the effects of mulching or green manuring and intercropping of a legume cover crops (*Crotalaria grahamiana*) as source of organic fertilizer supplement on potato growth and yield parameters. The experimental design was a randomized complete block design with 4 replicates and 3 treatments (T1: control, T2: intercropping + mulching with *Crotalaria grahamiana* T3: intercropping + green manuring with *Crotalaria grahamiana*). Results showed significant ($p<0,05$) positive effects of soil treatment with *Crotalaria grahamiana* on potato variety Bandy akama total tuber yields and on potato variety Meva height, stem fresh weight, total tubers number and yield, large-sized tubers number and yield as compared to control. Total tubers yield advantage was 92 to 115% on potato variety Bandy akama and 79 to 86% on potato variety Meva. Large-sized potato tubers yield advantage on variety Meva was 116 to 124%. Therefore, integration of *Crotalaria grahamiana* in farming systems has potential to sustainably enhance rural farm household income, food security and resilience to climate change.

Keywords: potato, cover crops, *Crotalaria grahamiana*, green manure, mulch, Vakinankaratra

Introduction

In Madagascar, as in other African countries, Agriculture plays a major role in supporting economic growth and social progress. This sector employs 80% of the workforce and contributes to 25% of GDP. An estimated 71% of farmers are smallholder farmers practicing subsistence-oriented farming on small land holdings less than 2 ha [1]. The population was estimated at 27.2 million people in 2020, with one of the highest growth rates in sub-Saharan Africa (3.0 per cent) [2].

Rice is the staple food especially in the most densely populated area, the Highlands. Following the saturation of wetland areas devoted to traditional irrigated rice production, smallholding farmers developed new farming systems based on upland rainfed on the hillsides.

The Vakinankaratra region, the second most densely populated region in the central Highlands is an area with high agricultural and pastoral vocation. The high altitude tropical climate and the presence of two types of soil (ferralsol and volcanic soil) has been particularly suitable for a wide variety of tropical (rice, cassava, sweet potato, maize…) and temperate crops (potato, fruits, wheat…) as well as livestock farming including dairy cattle farming.

The Vakinankaratra region is the main supplier of vegetable crops, especially potato and carrot as well as dairy products to the nearby markets of the capital Antananarivo [3]. Dairy production accounted for 80% of national production. The area under potato production in the Vakinankaratra region alone is more than 50 000 ha [4]. Potato is an important food crop in this region as it plays the role of rice supplement or substitute during the lean agricultural period in rural areas.

Despite the Vakinankaratra region's potential for agricultural development, poverty rate was high (75,8%) in 2010 slightly lower than the national average (76,5%), and level of food self-sufficiency is relatively low as reflected by longer period of basic foods purchase (from 5 to 7 months to a year) [5].

Several socio-economic and environmental constrains have hindered the agriculture sector's performance, whose effects are exacerbated by climate variability and change.

Demographic growth has brought about fragmentation and shrinking size of farming land inherited and shared over generations. Mean land-holding size is averaging 1,15 ha and 1,05 ha at the national and the Vakinankaratra region level, respectively [5].

Traditionally, production systems are based on extensive practices. The expansion of agricultural land has brought about massive deforestation, and adoption of environmentally non-friendly farming practices such as slash-and burn-agriculture. Natural and anthropic forces have driven soil degradation or soil erosion and nutrient loss in converted land declining yields and affecting, in turn the environment and the climate system. Soil fertility degradation is fostered by non-sustainable soil fertility management such as shortening or absence of fallow periods, non-return of nutrients to soil and low use of inputs associated with smallholding farmers' limited access to agricultural inputs eg improved seeds and mineral/organic fertilizer…).

In this context, the present study aimed to evaluate under field conditions the effects of a legume cover crops (*Crotalaria grahamiana*) intercropping and mulching or green manuring on growth and yield parameters of two widely grown potato varieties (Bandy akama, Meva) to sustainably improve rural household food security and income.

Materials and Methods

2.1. Experimental site

The present field study was carried out over two adjacent plots located at one site (19°49'39''S; 46°53'19''E, 1,576 m asl) at the rural Commune of Mandritsara, in the District of Betafo, in the Vakinankaratra region over two warm and rainy seasons, from November 2019 to May 2020 and from November 2021 to May 2021, respectively.The experimental site has tropical altitude climate with a dry and cool season extending from May to September with average daily temperature ranging from 8°C to 21°C and a rainy and warm season extending from October to April with average daily temperature ranging from 15°C to 26°C and a mean annual rainfall averaging 1333mm.

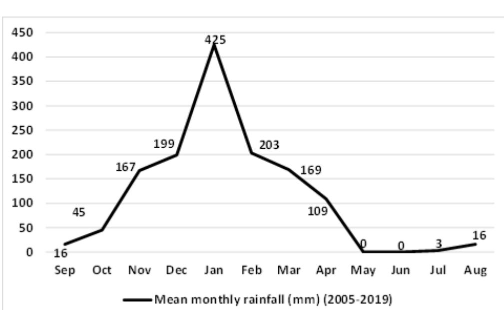

Fig.1. Mean monthly rainfall in the Vakinankaratra region (2005-2019)

Pre-trial composite soil sample taken form the experimental site, is tropical brown of recent volcanic origin, moderately acidic (pH = 4,82), relatively rich in carbon (4,20%) and in nitrogen (0,270%) with a satisfactory C/N ratio (13,9), moderately rich in phosphorus (3,5%) and in potassium (0,209%), with a loamy sand texture.

2.2. Treatments and experimental design

The potato variety Bandy akama used over the 2019-2020 field experiment is the first cultivated variety of potato in small-scale farming systems in the Highlands owing to its fair productivity performance under harsh environmental conditions.

The potato variety Meva used over the 2020-2021 field experiment is also a widely adopted and highly appreciated variety by small-scale farmers owing to its suitability to frying, its relatively short growth cycle (3 months) and its better prices or high economic value on the domestic markets.

The adopted cover crops *Crotalaria grahamiana*, is a perennial legume fairly adapted to agroecological zones of the Highlands, mainly grown as a hedge plant and a compost organic activator.

For both field experiment, the experimental design was a randomized complete block with three treatments and four replicates. Treatments were consisted of:

T1: monoculture of potato grown under standard fertilizer composed of 10t ha-1 of cattle manure and 33kg N + 66 kg P2O5 + 48 kg K2O ha-1 in the form of NPK complex 11-22-16 applied at potato planting time complemented with additional 46 kg N ha-1 in the form of urea applied four weeks after planting during earthing up time.

T2: mixture of potato and *Crotalaria grahamiana* in alternate rows where the legume cover crops was established in drill sowing pattern ten weeks prior to potato planting. Six weeks after sowing, legume crops aerial biomass was entirely cut down and allowed to die back during four weeks to form a mulch while the root systems remain in the soil.

T3: mixture of potato and *Crotalaria grahamiana* in alternate rows where the legume cover crops aerial biomass was entirely cut down and incorporated into the soil four weeks before potato planting, while the root systems remain in the soil.

2.3. Sampling and measurement

Measurements of potato growth (height, fresh aboveground biomass) and yield parameters [total tubers number and yield, large-sized (≥ 55mm diameter) tubers number and yield, medium-sized (28 to 55mm diameter) tubers number and yield, small-sized (≤28 mm diameter) tubers number and yield] were made on 12 potato plants located in the central two rows at 10 weeks and 12 weeks after planting, respectively.

At the end of the experiment, soil samples were taken in all plots, at the horizons of 0 to 15cm. Soil carbon, organic matter, nitrogen, phosphorus and potassium contents were measured.

2.4. Statistical analysis

Para-metric data were subjected to analysis of variance followed by means separation according to the Tukey's honestly significant difference test ($p<0.05$). For non-parametric data, Kruskal-Wallis test (α = 0.05) and then a pairwise comparison test was performed (α = 0.05) using the software XLSTAT.

Results and Discussion

3.1. Potato height and fresh weight aboveground biomass

Potato variety Meva height and fresh weight aboveground biomass at 10 weeks after planting were significantly ($p<0.05$) affected by soil treatment. Potato height was 29 % higher and 43% higher under treatment with green manuring + intercropping and mulching + intercropping with *Crotalaria grahamiana*, as compared to control, respectively.

Moreover, increased potato fresh weight aboveground biomass per plant under green manuring + intercropping (57%) and mulching + intercropping (91%) with *Crotalaria grahamiana*, as compared to control were noticed (Table 1).

Table 1: Potato variety Meva height and fresh weight aboveground biomass per plant according to soil treatment types (2020-2021)

Soil treatment	Plant height (cm)	Fresh weight aboveground biomass/plant (g)
Control	40.81 ± 7.58 b	34.20 ± 9.17 b
Mulching + intercropping with Crotalaria grahamiana	58.22 ± 7.77 a	68.20 ± 17.67 a
Green manuring + intercropping with Crotalaria grahamiana	52.64 ± 6.28 a	53.8 ± 18.68 a
P-value	<0,0001	0,049
alpha	0.05	0.05

Within columns means followed by the same letter are not significantly different at p = 0.05 according to the Kruskel-Wallis all pairwise comparison test

3.1 Potato tubers number and yield

Yield parameters at physiological maturity (12 weeks after planting) were significantly higher under soil treated with *Crotalaria grahamiana* for the two experimental potato varieties.

Total number of tubers per plant for the potato variety Meva was significantly ($p<0.05$) higher under treatment with green manuring + intercropping (38%) and mulching + intercropping (32%) with *Crotalaria grahamiana*, as compared to control (Table 2). No significant difference was noticed between *Crotalaria grahamiana* soil treatments. Large-sized (≥ 55mm diameter), marketable potato tubers number was 76 to 85% higher under *Crotalaria grahamiana* treatments but there was no significant difference between soil treatments regarding medium or seed-sized (≥ 28mm - 55mm diameter) and small-sized potato tubers (≤ 28mm) (data not shown).

Table 2: Potato variety Meva total and large-size tubers number according to soil treatment types (2020-2021)

Soil treatment	**Total potato tubers number/plant**	**Large-sized potato tubers number/plant**
Control	7.83 ± 3.79 b	1.83 ± 1.65 b
Mulching + intercropping with Crotalaria grahamiana	10.31 ± 3.73 a	3.39 ± 1.75 a

Green manuring + intercropping with Crotalaria grahamiana	10.83 ± 5.15 a	3.22 ± 1.74 a
P-value	0.005	0.001
Mean	9.66 ± 4.43	2.81 ± 1.84

Within columns means followed by the same letter are not significantly different at p = 0.05

Total tuber yield of potato variety Bandy akama was significantly (p<0.05) higher by 92% and 115% under soil treatment with green manuring + intercropping and mulching + intercropping with *Crotalaria grahamiana*, as compared to control, respectively (Table 3).

Table 3: Potato variety Bandy akama total tubers yield (2019-2020)

Soil treatment	**Total potato tubers (t/ha)**
Control	12,58 ± 6,15 b
Mulching + intercropping with Crotalaria grahamiana	27,05 ± 11,19 a
Green manuring + intercropping with Crotalaria grahamiana	24,15 ± 9,51 a

Within columns means followed by the same letter are not significantly different at p = 0.05 according to the Kruskel-Wallis all pairwise comparison test

Higher total tuber yield by 79% and 86% and large-sized tubers yield of the potato variety Meva by 116% and 124% compared to control were noticed under *Crotalaria grahamiana* green manuring + intercropping and mulching + intercropping, respectively (Table 4).

Table 4: Potato variety Meva total and large-size tubers yield according to soil treatment types (2020-2021)

Soil treatment	**Total potato tubers yield (t/ha)**	**Large-sized potato tubers yield (t/ha)**
Control	13.26 ± 5.81 b	6.32 ± 5.65 b
Mulching + intercropping with Crotalaria grahamiana	24.07 ± 8.67 a	14.14 ± 10.21 a
Green manuring + intercropping with Crotalaria grahamiana	23.75 ± 8.35 a	13.65 ± 6.28 a
P-value	<0.0001	0.001
Mean	20.36 ± 9.16	11.37 ± 8.39

Within columns means followed by the same letter are not significantly different at p = 0.05

At the end of the second field experiment (2020-2021), increased soil carbon (5 to 12,2%), organic matter (5,3 to 39%) and nitrogen (7,7 to 17,9%), content under soil treatments with *Crotalaria grahamiana* was recorded as compared to control (Table 5).

Table 5: Soil chemical properties according to soil treatment types

Soil treatment	C%	N%	Organic matter %	C/N	P(Bray II) ppm	K (meq/100g)
Control	4,26	0,273	7,33	15,6	4,90	0,288
Mulching + intercropping with Crotalaria grahamiana	4,78	0,294	8,22	16,2	4,20	0,283

Green manuring + intercropping with Crotalaria grahamiana	4,49	0,322	7,72	13,9	4,70	0,281

Soil treatment with either mulching and intercropping or green manuring and intercropping with the legume cover crops Crotalaria grahamiana positively affected growth and yield parameters of the two experimental potato cultivars.

Numerous studies have reported positive effects of intercropping, green manuring and plant residue mulching on potato growth and productivity.

Tankou et al., (2008) experiment showed that input of *Crotalaria grahamiana* green manure obtained from plants previously relay intercropped with potato or from sole cropping system (improved fallow) has potential to supplement mineral and organic fertilizer to sustain potato variety Spunta productivity enhancement in the Western Highlands of Cameroon [6]. Similar results with other green manure species were found by Kae et al. (2014) [7].

A field experiment carried out in Indonesia reported that rice straw mulch led to an increase in potato growth parameters over time [8]. At 10 weeks after planting, potato plant height, stem diameter and leaf number were 25%, 31% and 59% significantly higher under soil treatment with rice straw as compared to control.

Potato mulching with plant residue, especially rice straw led to significant increase of total tuber numbersand marketability of thetubers (higher than 28mm) [9].

Thor Smestad et al. (2002) field experiment in the Highlands of Kenya revealed potential of short fallow (total length including intercropped establishment of 31 weeks) with *Crotalaria grahamiana* to enhance subsequent maize crop growth and restore soil fertility and organic matter for the long term [10].

Positive effects of *Crotalaria grahamiana* mulching + intercropping or green manuring + intercropping on potato growth and yield recorded over the present field experiment can be associated with improved mineral nutrition or increased essential nutrients uptake as a consequence of modification of organic matter dynamics and soil nutrients especially nitrogen cycling.

According to Koch et al., (2020), apart from helping potato to better handle adverse growth conditions and promoting potato quality improvement, a sufficient supply of mineral nutrients is essential for achieving high yield [11].

Organic matter is a key component of soil that affects its physical, chemical and biological properties, which supports multiple ecosystem functions that are important for sustainable agriculture.

Frequent input of organic matter into soil through organic mulches, plant litter, roots organic compounds and fresh plant materials incorporation improves soil physical conditions, which in turn promotes nutrient availability and uptake by plant.

Soil physical conditions improvement includes improved tilth, increased aggregate stability, improved water and nutrients retention, reduced compaction and reduced erosion [12] [13].

Nitrogen is an essential macronutrient for plant growth and development. Several studies reported that increasing N supply impacts potato yield and increases percentage of large-sized, marketable tubers [14] [15] [16].

However, excessive supply of nitrogen may favour potato stem and leaves growth at the expense of tuber development/maturity and quality as a consequence of diverted energy for supporting vegetative growth [17].

Cattle manure is an important source of nutrients for Malagasy smallholder farmers. It is the most commonly used fertilizer applied at limited quantities less than 5 tons ha-1 per year [18].

In the Vakinankaratra region, where mixed farming systems are broadly practiced, cattle manure efficiency is limited by variable crop-livestock ratios and variable livestock and manure handling.

Due to poor organic matter content of small-scale farm soils in the Highlands, *Crotalaria grahamiana* integration in farming systems has potential to improve soil nutrients management to supplement cattle manure and enhance potato growth and yield.

Conclusions

Major conclusions of the present field study are as follows:

(i). *Crotalaria grahamiana* mulching/green manuring and intercropping with potato has significant positive effects on the two varieties of potato growth and yield components.

(ii). Integrating the legume cover crop *Crotalaria grahamiana* in small-scale farming systems has potential to supplement cattle manure, improve soil fertility management and enhance rural farm household income, food security and resilience to climate change.

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