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Organic Fertilization of Potato (*Solanum tuberosum*) with Green Fertilizer (*Tithonia diversifolia*)

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ABSTRACT

The present study was conducted on the volcanic soil of Mudja in Nyiragongo territory to evaluate the effect of fresh biomass of *Tithonia diversifolia* on the productivity of different potato varieties (*Solanum tuberosum L.*). The experimental set-up was a completely randomized block design with four replicates and three treatments. *Tithonia* leaves were incorporated into the soil two weeks before planting potato tubers at a quantity of 36 kg. The results showed that the general trend in plot productivity was in the order of : T3>T1>T2 with the Gahinga variety (T3) at 27.81T/ha. The study showed that *Tithonia diversifolia*, under the conditions of this trial, had great potential for improving soil nutrient availability and could supply the quantity of nutrients required for potato cultivation without using chemical fertilizers.

INTRODUCTION

Despite its importance, the development of the potato sector has been hampered by a number of constraints, including: the exhaustion of land used without restitution, and a lack of robust varieties well adapted to different growing conditions. Potatoes are one of the most important food crops in the high-altitude regions of eastern DRC. Along with wheat, rice and maize, it is one of the most important crops, providing food and economic support to a large number of the DRC's inhabitants, particularly in North Kivu (AgriProfocus DRC, 2014). In 2014, global potato production was estimated at 385 millions tons, for a cultivated area of 18.8 millions hectares, with an average yield of 20.51 tons/ha (Mongana, 2018). In the DRC, the average yield is 6-7 tons/ha. The potential yield of improved varieties is between 10 and 15 tonnes/ha at farm level, and 20 to 30 tonnes/ha at research station level (INERA Mulungu, 2003).

Low potato yields are due to growers' lack of knowledge of the fertilization balance (CDE and CTA, 2014). Among the causes of this drop in production are soil infertility, the high cost and unavailability of fertilizers, making them almost inaccessible to small-scale farmers (Jama B. and al., 2000). The loss of soil fertility in the DRC is a consequence of the continuous use of soil organic matter without any exchange. Considering the high cost of mineral fertilizers, optimizing fertilization is of the utmost importance, especially as potatoes react strongly to them (Kaho *et al*., 2011). In such a context, organic fertilization should be an appropriate solution for restoring soil fertility (Bilong *et al*., 2017). Moreover, recent studies have shown that soil productivity in the tropics declines even with the continued use of chemical fertilizers alone. Among the plants of choice for supplying raw material for organic soil improvers, *Tithonia* has attracted the attention of several authors (Motis, 2017). With this in mind, the potato was studied to improve its production through fertilization. In addition, we would like to know which of the three potato varieties used would respond better to *Tithonia* fertilization? Based on the question posed above, our hypothesis is as follows: One of the potato varieties used should respond favorably to *Tithonia diversifolia* fertilization. Research into agroforestry species with potential for improving soil fertility has focused mainly on nitrogen-fixing legumes, with very little attention paid to non-nitrogen-fixing species. There is therefore a need to evaluate other species with a view to diversifying the options available and reducing growers' dependence on a few species. Specifically, this study will confirm that *Tithonia* can be used as an alternative to nitrogen-fixing species (Jama *et al*., 2000).

LITERATURE REVIEW

The potato originated in the Andes (Peru). It is grown in mountainous regions, generally at altitudes of over 2,000 m (Hijmans, 2001). The potato is an herbaceous, tuberous plant with an upright growth habit that can reach a height of 1 m, more or less spreading with age (Vandenput, 1981). Botanically, it is not a root vegetable but a stem vegetable: the tubers are transformed underground stems. The vegetative cycle varies according to variety, growing for 90-110 days. The root system is fasciculated and highly branched; it tends to spread superficially but can grow up to 0.8 m deep. The various varieties differ in flesh colour, tuber shape, dormancy and storability (Heuzé *et al*., 2016). Potatoes require a temperate climate. In the DRC, it is grown almost exclusively in the highlands of the east and in Katanga; it is a hardy plant that is resistant to

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cold and heat. The potato prefers light (sandy or sandy-loam), slightly acidic soils (pH 5 to 6.5). The light soils of volcanic origin in North Kivu are particularly well-suited to its cultivation. To tuberise, it needs cool temperatures of between 10° and 15°C.

Varieties are selected on the basis of productivity, earliness, disease resistance, eye sunkenness, flesh colour, cooking content, taste and protein content. The first thing to do when preparing the soil is to ensure that it is well loosened and at a depth that allows the rootlets to develop, the tubers to grow as evenly as possible and important water reserves to accumulate. Deep ploughing (30-40 cm) is carried out, followed by several weeding operations (Muna-Mucheru, 2007). The tuber begins its development cycle as soon as it germinates and, whether planted or not, it will tuberise after a period corresponding to its maturity (length of cycle). Before harvesting, tuber maturity is determined (when the plants reach the end of their cycle) by vegetation that begins to yellow and wither, known as senescence. The length of the cycle is strongly influenced by the physiological stage of the plant used. It's easy to check whether the tubers are ripe for harvesting. The skin must adhere to the tuber after giving it a nudge (CDE, 2014). Once any injured tubers have been removed, the crop is stored in an airy, dry room away from light.

Fertilisation practices have a major influence on the yield and quality of the potato harvest. Potatoes require a lot of minerals, especially potash. Fertilisation involves the use of organic fertilisers (manure, compost, green manure), which are useful for improving soil structure and are applied before the crop is grown to allow mineralisation. Fertilisers are classified either according to the number of N, P and K elements provided (simple fertilisers provide only one, compound fertilisers at least two) or according to their origin (organic or mineral fertilisers) (Muna-Mucheru, 2007). Nitrogen is essential for tuber growth, but it also encourages the development of vegetation, to the detriment of tuber formation if there is too much. Potato yield is very closely linked to the availability of mineral elements, and deficiencies will have a direct impact. So, sufficient but not excessive fertilisation will be a major element of success for the quantity, quality and profitability of production (CDE, 2014). There are certain simple principles that make it easier to adapt fertilisation to the production envisaged. However, the laws of fertilisation must be applied with discernment.

The aim of mineral fertilisation is, of course, to provide the plant with all the mineral elements it needs, when it needs them. Organic fertilisers are compound fertilisers (providing N, P, K) but they also provide all the other macros or trace elements contained in living matter. Very rich in nitrogen, they encourage microbial life and humification. These are non-water-soluble fertilisers, which are not immediately assimilable. They must first undergo mineralisation processes. They are therefore bottom-dressing fertilisers, with a regular, prolonged action that protects nutrients from leaching (Heuzé *et al.*, 2016). Organic fertilisers alone are insufficient to compensate for low nutrient levels in tropical soils (Muna-Mucheru, 2007). The beneficial effects of organic fertilisers on the physico-chemical and biological properties of the soil, and hence on plant growth, would make the use of modest doses of mineral fertilisers more effective (Jama *et al.*, 2000).

However, the success of this strategy will depend on the quality of the organic material used and the quantity of nutrients contained in that material. In view of the importance of fertilisation, the high price of mineral fertilisers and the scarcity of organic matter, it is essential that growers take every possible precaution to initiate rational fertilisation, incorporating good crop rotation and the use of green manures. Incorporating the biomass produced by selected species into the soil is beneficial, as its decomposition in the soil improves its structure and returns a significant quantity of fertilising elements. Plants of the *Tithonia* genus, for example, are used for this purpose. Under normal growing conditions, the potential yield is around 20 to 30 tonnes per hectare. In tropical Africa, however, it is much lower in reality, with national averages of around 10 T/ha. Degenerate seed material (viruses, vascular bacterial disease), a shortage of quality seeds, acid or poor soils, a lack of organic or mineral fertiliser, and a lack of means of combating fungal diseases (mildew) go a long way to explaining this low productivity.

MATERIALS AND METHODS

Study Environment

This experiment was carried out in the village of Kanyati, in the Mudja group, at an altitude of 1550 m,

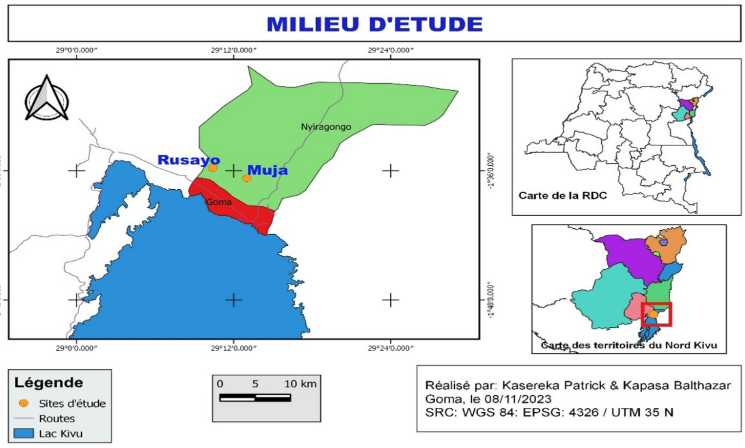

Figure 1: Location of the study area

1° 30' 36" South latitude and 29° 14' 39" East longitude, where temperatures vary between 15 and 30°C. Rainfall is abundant and the rainy season is longer than the dry season. The soil of Mudja is described as andosols derived from eruptive rocks.

Materials

Biological Materials

The potato seeds used are : N'simira variety, Cruza 148 variety and Gahinga variety and have almost similar characteristics in terms of environmental conditions and cultivation technique (SENASEM and CTB, 2008). Tender stems of *Tithonia diversifolia* were also used as green manure, and buried in the soil a week before planting.

Non-Biological Equipment

These are the technical materials used to carry out the work involved in this experiment. These include Machete, hoe, hoe, string, stakes, hand sprayer or Gand sprayer, GPS / Garmin, ordinary scale, tape measure, caliper.

METHODOLOGY

Experimental Set-Up

The design used in this experiment was completely randomized blocks with 3 treatments and 4 replicates, giving 12 plots. Blocks and plots were separated by 1 m, and plots had a surface area of 6 m² each.

Legend

- ✓ T1: N'simira variety, fertilized with *Tithonia diversifolia*

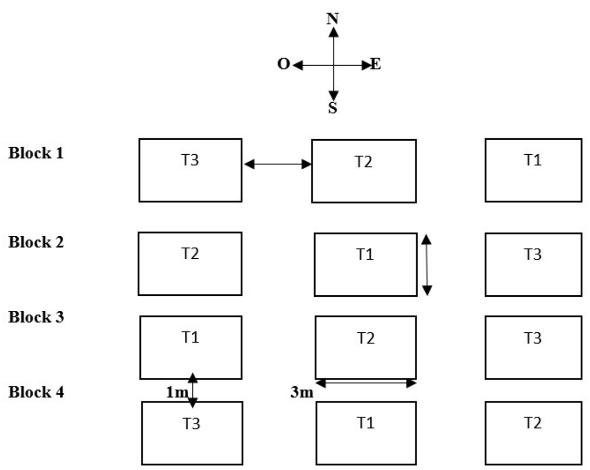

Figure 2: Diagram of experimental set-up

- ✓ T2: Cruza 148 variety, fertilized with *Tithonia diversifolia*
- ✓ T3: Gahinga variety, fertilized with *Tithonia diversifolia*

Conduct of the Experiment

Ploughing was carried out with a hoe, and the soil was loosened and levelled with a rake for all treatments. Plot preparation and *Tithonia diversifolia* burial were carried out at the same time. Planting took place two weeks after burying the *Tithonia*. Planting was done in rows, 40 cm x 50 cm apart. The result was 4 rows of seedlings per plot, including 28 bunches, since one tuber was planted per bunch.

The quantity of *Tithonia diversifolia* that was buried was calculated as follows:

Recommended quantity = 5 T/ha

1 ha = 10000 m² and 5 Tons = 5000 Kg

Quantity used : 10000 m² → 5000 Kg

72 m² → (5 000 X 72)/(10 000)=36 Kg of *Tithonia*

The maintenance treatments applied were weeding, hoeing and ridging. These were carried out every 15 days on all treatments. The first hoeing and ridging took place 3 weeks after planting. The phytosanitary treatment used was a bio-pesticide made from sage. The treatment was applied by spraying.

Observed Parameters

Vegetative Parameters

These were obtained by observing the potato vegetative cycle from sowing to harvesting.

Emergence Rate

Obtained by dividing the total number of tubers planted by the total number of tubers germinated, multiplied by 100. This observation was made 3 weeks after planting. This parameter was determined by simple counting.

Diameter at Collar (in cm)

This parameter was observed from one month after planting and measured using a caliper placed at the plant's collar to determine its diameter. This was repeated three times during the trial.

Average Stem Height (in cm)

Using a tape measure, we were able to determine plant heights according to treatment averages.

Tuber Diameter

Obtained by rolling the tape measure along the length of the tuber to determine its diameter.

Production Parameters

Number of Tubers Per Plant

This was obtained by a simple count of the tubers produced by each plant;

Weight of a Tuber Per Plant in Grams

Obtained by weighing a tuber on an ordinary scale;

Average Tuber Weight Per Plant in Kilograms

Obtained by weighing the tubers obtained per plant on an ordinary scale.

Plot Production in kg

Obtained by weighing tubers on a small plot, experimental unit or treatment.

Yield in Tons Per Hectare

Plot production extrapolated to the hectare.

Data Dnalysis

Two-criteria analysis of variance classification (ANOVA II) and separation of means (PPDS Test) were used to determine differences in means between treatments, as treatments and blocks were the sources of variation in addition to experimental error, using MS Excel 2010 and GenStat Discovery Edition 4 software.

RESULTS

Chemical Composition of *Tithonia* Diversifolia Biomass

Table 1 shows that the nitrogen content of *Tithonia* leaves is comparable to that of most species used in agroforestry to improve soil fertility. As for P and K contents, they are much higher than those found in other species. The ability of an agroforestry species to improve soil productivity depends on its biomass yield, the quality of this biomass and its decomposition rate. Analysis shows that *Tithonia* leaves are very rich in nutrients and easily decomposable.

Vegetative Parameters

Table 2 shows separately the average data for emergence rate, crown diameter, plant height and tuber diameter harvested throughout the trial.

Table 1: Nitrogen (N), phosphorus (P) and potassium (K) content of various *Tithonia diversifolia* plant tissues

Plant tissue	**% N**	**% P**	**% K**
Leaves (new growth)	5,70	0,52	2,83
Stems (new growth)	1,96	0,46	3,08
Mixture of leaves and stems (new growth)	5,66	0,52	2,58
Old decomposing leaves (litter)	2,67	0,38	0,58

Source : Tim Motis, 2017 : Tithonia as green manure (www.echocommunity.com)

The table shows that emergence was effective, with average emergence rates of 92.5% for T2 and T3 and 87.5% for T1. The average tuber diameter for all treatments was 40.98 mm. As neck diameter is an important element in assessing the vegetative development of plants, the table below illustrates this observation. The table shows that the diameter at the neck is the same for all treatments. The table also shows that T1 and T3 have greater plant height than T2.

Table 2: Results for vegetative parameters

		Emergence rate (in %)	**Diameter at collar (in cm)**	**Plant height (in cm)**	**Tuber diameter**
		$\bar{x} \pm \sigma$	$\bar{x} \pm \sigma$	$\bar{x} \pm \sigma$	$\bar{x} \pm \sigma$
T1	N'simira variety	$87,5 \pm 9,57^{a}$	$0,8 \pm 0,10^{a}$	$51,7 \pm 4,63^{a}$	$40,56 \pm 1,15^{a}$
T2	Cruza 148 variety	$92,5 \pm 5,00^{a}$	$0,8 \pm 0,05^{a}$	$45,4 \pm 7,59^{b}$	$41,60 \pm 3,67^{a}$
T3	Gahinga variety	$92,5 \pm 9,57^{a}$	$0,9 \pm 0,05^{a}$	$48,3 \pm 6,23^{ab}$	$40,77 \pm 1,27^{a}$
PPDS		**12,90**	**0,09**	**6,16**	**2,615**

Means assigned the same letters are not significantly different at the 5% probability level.
Source: Our experiment, 2019
Legend: T=Treatment, $\bar{y}$=Mean, σ=Standard deviation, PPDS=Poorest significant difference

Production-Related Parameters

Results for production-related parameters are presented in Table 3 below:

In terms of production, the number of tubers a plant produces is an important observation. Statistically, the averages in this table show that all treatments had the same number of tubers per plant. The table shows that, statistically, treatment T3 had a higher tuber weight than the other treatments. From this table, we can see that the average tuber weight per plant is higher for T3, followed logically by T1 and then T2. Based on the PPDS, we can see that *Tithonia* reacted differently to the plot production of all treatments, since the T3 averages are higher than the averages of the other treatments. The data in the table above are conclusive on the yield of the trial. Coefficient of variation values reveal a wide dispersion within all treatments. At the 5% probability threshold, the difference is significant for the treatment factor, so it had an effect on plot tuber production in Kg.

Table 3: Production-related parameters

		Number of tubers per plant	**Average weight of a tuber per plant in g**	**Average weight of tubers per plant in Kg**	**Plot production in kg**
		$\bar{x} \pm \sigma$	$\bar{x} \pm \sigma$	$\bar{x} \pm \sigma$	$\bar{x} \pm \sigma$
T1	N'simira variety	$9,00 \pm 0,00^{a}$	$150 \pm 103,08^{ab}$	$1,35 \pm 0,93^{ab}$	$14,33 \pm 8,96^{ab}$
T2	Cruza 148 variety	$8,75 \pm 0,50^{a}$	$120 \pm 43,49^{b}$	$1,05 \pm 0,41^{b}$	$10,17 \pm 4,05^{b}$

T3	Gahinga variety	8,75 ± 0,50[a]	180 ± 25,00[a]	1,57 ± 0,33[a]	16,69 ± 3,92[a]
PPDS		**0,763**	**58,6**	**0,514**	**6,50**

Values with the same letters are statistically identical at the 5% probability level.
Source: Our experiment, 2019
Legend: T=Treatment, ȳ=Mean, σ=Standard deviation, PPDS=Poorest significant difference

General Trend in Yield by Treatment
The figure shows that T3 has the highest production at 27.81 T/ha, followed by T1 at 23.88 T/ha. The mean values of the treatments above the histograms are significantly different.

The results of the analysis of variance relating to yield reveal a significant difference between treatments. The comparison of means test enables us to classify the yield averages in tonnes per hectare shown on the graph above into different classes.

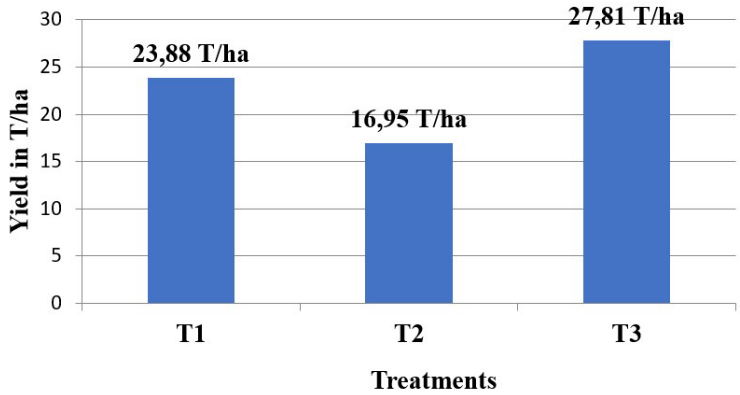

Figure 2: General trend in potato production according to treatment applied

Table 4: Analysis of variance for yield in T/ha

Source of variation	d.l.	s.c.	c.m.	F.cal.	P-Value	Decision
Blocks	3	460,27	153,42	1,94	0,022	S
Treatments	2	242,53	121,27	1,54	0,028	S
Résidual	6	473,34	78,89			
Total	**11**	**1176,14**				

DISCUSSION
Table 1 shows that *Tithonia* leaves contain nitrogen levels comparable to most species used in agroforestry to improve soil fertility. However, from an environmental point of view, the promotion of this strategy should depend on controlling the acidifying effect of this plant (Anjarwalla *et al*., 2016). After our statistical analyses, we found that from a vegetative point of view, our observations showed a better behavior of all treatments against *Tithonia diversifolia*. This is illustrated by the good collar diameter and plant height, which were always satisfactory, as shown in Table 2. Good vegetative growth is a key factor in achieving good yields. With regard to production-related parameters, our observations sufficiently revealed through the different averages in Table 3 that *Tithonia diversifolia* had a significant impact on potato tuber production. These results corroborate those of Kaho *et al*. (2011) in Cameroon, who showed that the addition of *Tithonia diversifolia* green biomass improved soil fertility and maize and tomato production. The decomposition of *Tithonia* enriches the soil with organic matter, which benefits the plant. *Tithonia* improves soil structure, despite the need for weeding (Jama *et al*., 2000). Although organic matter releases nutrients slowly, it ensures that soil structure is maintained. In terms of yield, treatment T3 (Gahinga) was better than the other treatments, with an average of 27.81 T/ha. This does not deviate from reality as described by SENASEM, 2008, which states that potato yields, particularly of the Gahinga variety, can vary between 20 to 30 T/ha on research stations and 12 to 18 T/ha in rural areas. Of all the treatments, *Tithonia diversifolia* showed its limitations in terms of both vegetative and production parameters, giving a response trend to *Tithonia* in the order of T3 - T1 - T2.

CONCLUSION
The results of this study have shown that, in addition to the nitrogen-fixing species commonly used in agroforestry, other (non-nitrogen-fixing) species, including *Tithonia diversifolia*, can improve soil fertility and significantly increase crop yields from one environment to another. Further studies are needed, however, to quantify the sustainability of this effect (N'Dayegamiye &

Deschênes, 2014). With regard to vegetative parameters, our statistical analyses show that the blocks had an effect on the vegetative growth of the crop, which explains the differences in averages observed on stem versus plant height. The analysis applied to the averages of production-related parameters sufficiently confirms that there was a treatment and block effect on realized yield (Table 3). That said, the hypothesis that one of the three varieties would respond better to *Tithonia diversifolia* fertilization is confirmed, as the Gahinga variety showed better agronomic behavior in this experiment. We can say that *Tithonia diversifolia* as a green manure influences production more than mineral fertilizers from the second year after application (Kaho *et al*., 2011). As a result, the years following the application of *Tithonia*, which has decomposed well, will be productive. In addition to the difference in production achieved at the end of this experiment, the realities as described by RAEMAEKERS (2001) are not far from those encountered in the farming environment.

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