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INVESTIGATING THE OPTIMUM DENSITY OF PLANTATION OF NOBLE *SACCHARUM OFFICINARUM* CANES UNDER CERTIFIED ORGANIC CONTEXT USING LEAF AREA INDEX

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ABSTRACT

Noble sugarcanes are used in several cases of rum production and have a specific agronomic behavior as their morphologic characteristics are different from those observed in modern cultivars. Their height and tillering don't allow good yields under conventional methods of cultivation. They produce less stalks than modern cultivars on the same plant. Therefore, to get the same quantity of stalks per unit of surface, the population density has to be changed from standards. To study the impact of different densities on the cultivation of noble canes, the leaf area index (LAI) of noble and modern varieties was measured to know their capacity to cover the soil and prevent weed development. The cultivar To re'are'a (*S. officinarum* noble variety) was used with good agronomic potential, on an experimental plot of 4 000 m2 where two densities of plantation from 20 000 to 40 000 plant per hectare were compared, under the same cultivation standards. The doubled density plots showed better LAI (4,52 compared to 2,25 for low density), which increased month after month. Indeed, biomass yields were also higher (108,0 compared to 47,5 t/ha for the low density). Doubling the density of this noble cane could be a good agronomic practice to explore some better schemes of cultivation, adapted to organic agriculture. A special focus will be put on an intergeneric hybrid of *Saccharum officinarum x Miscanthus floridulus* called To 'a'eho (LAI = 6,65) to investigate the management of weeds inside the row.

Key-words: *Saccharum officinarum, Leaf Area Index, population density, plantation, noble sugarcane, organic agriculture.*

INTRODUCTION

Density of conventional sugarcane plantations is worldwide accepted at around 20 000 plants/ha (standard 1,8m row spacing also called inter-row) mainly depending on mechanized operations such as plantation and harvest (Fauconnier, 1991). Density also depends on the context, for example, if needed, inter-row can be reduced at minimum 0,9m or applied in paired rows such as 30:150cm with good results (Kumawat and Dahima, 2016). Therefore, in Reunion Island, where paired rows 50:140cm are usually applied (Poser et al., 2018), temperatures and soils are different following altitude and it has an influence on weed growth but also on both vegetative cycle and maturation of sugar and the density of plantation has to be adjusted following these parameters (Pouzet and Lienhart 1998;. Pouzet et al., 1999). Under organic sugarcane farming systems, minimizing row spacing is expected to preserve the soil from solar exposure and reduce weed development. It allows the plants to close the rows as soon as possible, but at the same time, row spacing has to be sufficiently wide to allow mechanized weed removing (Vitrac et al., 2019a). This is particularly true with varieties of noble *Saccharhum officinarum* which grow slower than *Saccharum* spp. (Vitrac at al., 2019b). As *Saccharum officinarum* noble canes are not cultivated any more from the beginning of the 20th century, very few studies were conducted on its growth and all agronomic parameters. However, there is a very special interest regarding these old varieties in small contexts of high valuable rum production (Vitrac et al., 2018a). Some distilleries in the Caribbean and Polynesia are used to produce rum with them and also under organic certified standards. They believe that old *Saccharum officinarum* varieties can bring to the rum very special aromatic flavors. For example, in the island of Tahiti, Vitrac *et al*. (2019b) showed the historic interest of Otahiti variety as they explored its culture under organic standards. These authors have proposed a list of pests regarding weeds (Pouzet et al., 1999) and also regarding other arthropods and rats (non published data). They finally concluded that conventional density of plantation is unadapted to *Saccharum officniarum* global production.

Vitrac *et al.* (2019a)) showed that modern *Saccharum* spp. have a tillering about 8 stems per plant contrary to some *Saccharum officinarum,* used for rum production, which had about 4 stems per plant. The hypothesis was then to double the density of noble cane to get the same amount of stems per unity of surface than *Saccharum* spp. increasing then the biomass production. Increasing density should also influence the capacity of the plant to capture the light to produce sugar and to reduce the weed development (less access to light by covering the soil), as the LAI (Leaf Area Index) increases the efficiency to capture light (Launay et al., 2019). We based our observations using a LAI approach to: (1) determine the theorical LAI of the varieties used and (2) measure the evolution of LAI for standard and doubled densities. The biomass yields comparing these two densities were also measured. Finally, in our experiments and measurements, the variety of *Saccharum maximum* called To'a'eho showed a very high theorical LAI. Due to this specificity, we discuss in this paper the interest of using this native intergeneric

hybrid *Saccharum officinarum* x M*iscanthus floridulus* (Vitrac et al., 2018a)) as a mean for organic weed management with the great interest that it could be harvested at the same time than *Saccharum officinarum* noble canes for rum production with a Brix degree of more than 16° (Vitrac et al., 2018a).
The objectives of this study is (1) to determine theorical LAI of sugarcanes as some *Saccharum* sp. modern cultivars, *Saccharum officinarum* cultivars and To ‘a’eho intergeneric hybrid (*Saccharum officinarum* x M*iscanthus floridulus*), to (2) propose a strategy of biomass yield improvement of *Saccharum offciniarum* To re’are’a doubling the density of standard plantation (20 000 to 40 000 plants/ha) and characterize it by a LAI approach to help the rum producers demand.

MATERIAL AND METHODS

Agricultural practices in organic sugarcane

All the fields studied were organic certified for both European (UE) and Pacific rules (NOAB, in French language: Norme Océanienne d’Agriculture Biologique). Vitrac et *al*. (2018a) defined the following soil preparation and cultural practices: before planting, the soil was worked to a depth of 15 cm then furrowed in twin rows, close together: 50 cm and distant from each other’s of 1.60 m. This spacing of 1.60 m (inter row) allows the passage of a small 4x4 tractor of 16 Horsepower (HP) equipped with a rotary cutter with blades allowing the mechanical weeding over 1.1 m in width. The arrangement in double rows makes it possible to densify the planting, the double row having to end up merging into a single and wide row. Due to the scarcity of plant material from recent local surveys, planting was carried out with 8-week-old plants raised in the nursery from one-eye cuttings (Poser et al., 2018). The seedlings were manually transplanted into the furrows at 50 cm intervals and in staggered rows, their survival rate was close to 100%. The weeding on the row was carried out using a “serpette”, the local name for a small manual hoe.
Organic compatible organo-mineral fertilization consisted of three inputs of distillery vinasses (20 t/ha, source of K), composted horse manure (5 t/ha, source of NP) and crushed dolomite (2 t/ha, source of CaMg), applied directly, mainly in the rows at the foot of the canes. These organic fertilizers were applied for the first time after the first post-planting weeding. Rainfall and temperatures were recorded using an automatic gauge between January 2018 and October 2020.

Experimental plots

An experimental collection plot (17°43'49.1"S 149°34'47.7"W) about 240m2 was installed in December 2019 with 16 sugarcane varieties: imported noble *Saccharum officinarum* (Black Cheribon (BC) and Batavia (BAT) from Cirad visacane®); modern varieties *Saccharum spp.* (Jaune roseau (JR), B69566 from visacane®, Rouge à Reflets Verts (RRV) and Blanche (Bla)); Polynesian noble *Saccharum officinarum* (irimotu, o’opu, ute, piavare, jaune à tâches rouges (JTR), rutu, re’are’a, oura and pourpe à bandes vertes (PBV)) and Polynesian *Saccharum* *maximum* (to'a'eho). For each variety, 60 plants were planted on 2x6m plots, with about 0,5m row spacing (20 000 plants/ha), without any replications.

On 19th of October 2020, 3 plants were sampled to measure the LAI (Leaf Area Index) with the method described by Hermann & Câmara (1999) in the following procedures: for each plant; (i) on the main stem we counted the number of green ray leaves (first fully emerged leaf at the top with a visible dewlap at the junction of the leaf blade and the leaf sheath) on the main cane stalk and for each leaf its length and width were measured; (ii) the number of tillers was determined and for each tiller the number of green ray leaves (N), their length (l) and width (w).

Leaf surface : Ls= l*w*0,75*(N+2) ; 0,75 being the coefficient of leaf shape

LAI : (Ls(main stem)+ Ls(tillers)*tillers average *(density(plant/m²)).

Additional "Fischer" experimental plot

This site (17°45'30.1"S 149°17'21.4"W) was the first plantation of organic certified sugarcane plants in 2013 on old pineapple fields stopped in 2007. It was renewed and grown with varieties of noble canes in 2016 on 4 000 m^2, a plot where most of the research program regarding noble varieties were usually conducted from 2016 to 2019 (Vitrac et al., 2018a).

In April 2020, it was renewed for the second time on the same surface. The variety chosen was re'are'a (called JRP (Vitrac, 2019b)) because of its good yield potential despite low tillering which is the component to improve. For each density, 3 doubled rows were planted with two densities tested: 20 000 plants/ha (d1) and 40 000/ha (d2), the only difference being the space of 25cm between each plant on the same row (d2) compared to conventional practice at 50cm (d1). A Fisher plot design was implemented with 3 blocks following a regular slope about 3% (Figure 1).

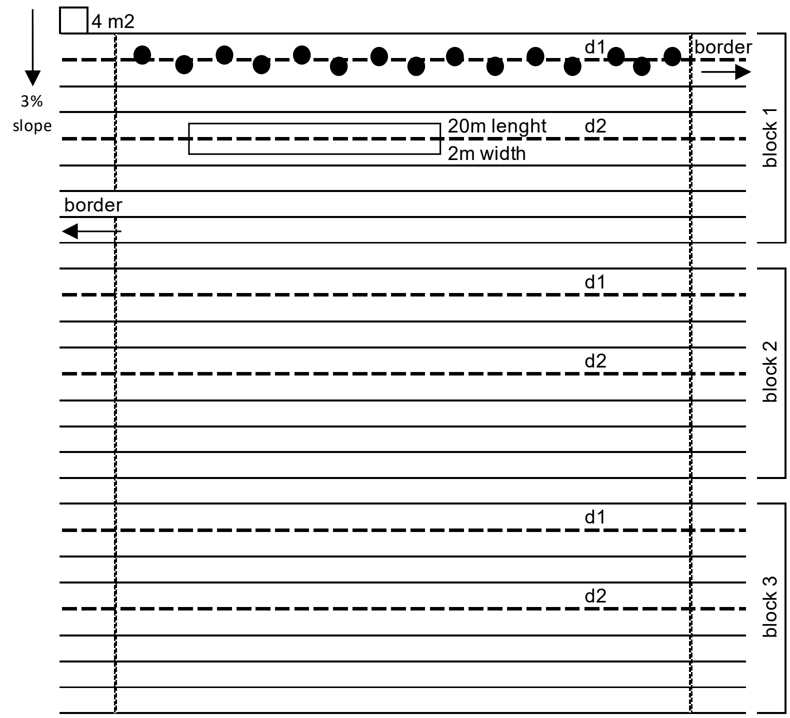

Figure 1: Fischer plot design of the additional experimental area. d1 (20 000 plants/ha) was compared to d2 (40 000 p/ha). 15 plants were sampled on the middle row to avoid border effects (black circles). Plants were counted inside an area about 20m length around the row to determine the measured density.

Measurements

Regarding the "Ficher" additional plot, ray leaves surfaces were measured and repeated every 4 weeks which is the necessary time for the plant to produce 3 new leaves (Castro-Nava et al., 2016). These measurements were conducted on 15 plants on 13/10/20, 19/11/20, 15/12/20 and 08/01/21 (Figure 2) in the middle row of each density to avoid border effects (Figure 1). Inside this row, we counted the number of plants for 40m2 (20m length x 2m corresponding to the width of the row) to determine the "measured density". Measured leaves were marked to sample only the new leaves.

For each plant we measured the number of stalks, the number of ray leaves per stalk, the length (l) and the width (w) for each ray leaf. Global Leaf surface (Ls= l*w*0,75*(N+2) ; 0,75 being the coefficient of leaf shape ; number of green ray leaves (N), their length (l) and width (w)) was then determined following method proposed by Hermann & Câmara (1999) and LAI as well by the following: LAI = (Ls(main stem)+ Ls(tillers)*tillers average *(density(plant/m²)).

The theorical yields were measured by harvesting stalks 15 samples. They were then weighed and multiplicated by the “measured density” and then reported to the corresponding surface of soil and yield finally estimated in tons / ha.

Statistics

Regarding the Fischer plot design and in order to compare the two densities d1 and d2, data were analyzed using the statistical software XLSTAT 19.4.45191. A population probability law (normal distribution) and descriptive statistical parameters such as mean and standard deviations were processed. Means comparison tests of Mann Whitney (samples<30) were used to compare LAI and weighed biomasses.

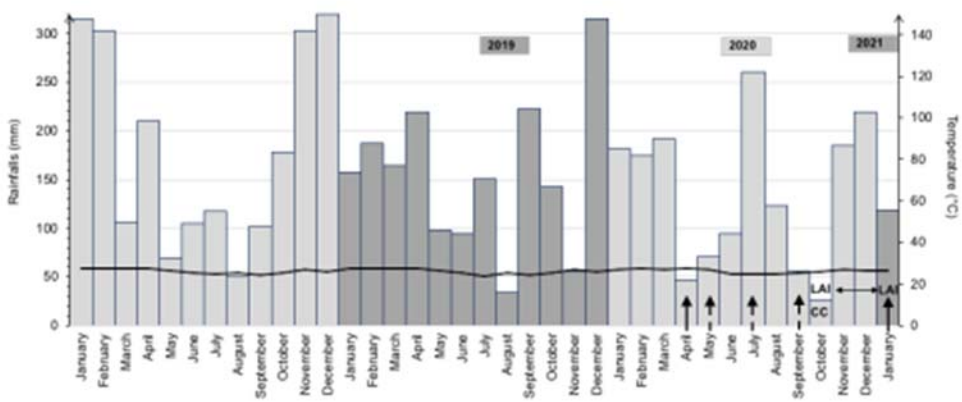

Figure 2: Pattern of rainfall and temperatures and successive operations since planting in April 2020 for the “Fischer” plot (black arrows show plantation and harvest in late January 2021). Discontinued black arrows (May, July and September 2020) shows operations of maintenance (mechanical and manual weed removing). CC: Cane Closure of rows; LAI: period of LAI sampling.

RESULTS AND DISCUSSION

In the experimental collection plot, modern varieties theorical LAI averaged is about 5,18 (Figure 3). It was significantly higher from both native and imported noble *Saccharum officinarum* (p=0,05) which had an average LAI between 2,69 and 3,34. This result confirms the observations of Vitrac *et al*. regarding tillering of noble varieties which have less stalks per plant than modern cultivars and consequently less leaves and soil covering aptitude as well. It confirms too the hypothesis that we can improve soil covering of cultivated noble canes by doubling the density of plantation. It is especially the case for the plot regarding the chosen re’are’a variety (LAI =1,83).

The LAI values we found regarding the “Fischer” plot experimentation with re’are’a variety were between 3,75 and 4,52 for doubled density (d2, Figure 4), which is a little bit more than what (Gomes da Silva et al., 2017) found for modern varieties (between 3,66 and 4,46). Therefore, for simple density (d1) the LAI were between 1,72 and 2,25 which is close to theorical the value of 1,83 which is the lowest (Figure 2). However, Vitrac *et al*. showed it has the highest biomass yield of *Saccharum officinarum* canes tested. It confirms that doubling the density of plantation of noble *Saccharum officinarum*, by using the method we propose, can improve their LAI so it can reach the level of modern varieties. To resume, it can reach a LAI about 4,52 when its density is doubled, becoming close to modern varieties (13).

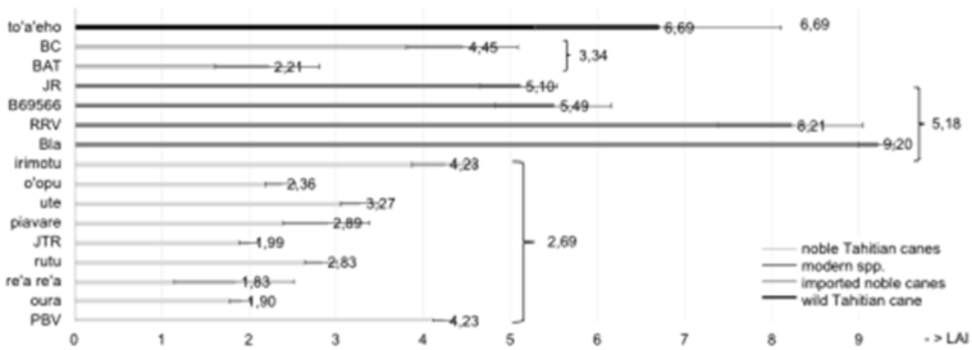

Figure 3: Theorical LAI values of all canes estimated in the experimental collection plot and average LAI of cane categories.

We observed no significant difference between the periods tested (p=0,05) for both d1 and d2 (which were significantly different, p=0,05) and a very small LAI increase from the first observation to the last (Figure 4). Actually at 220 days of growth, the rows were already closed and the LAI values observed were only linked to the density.

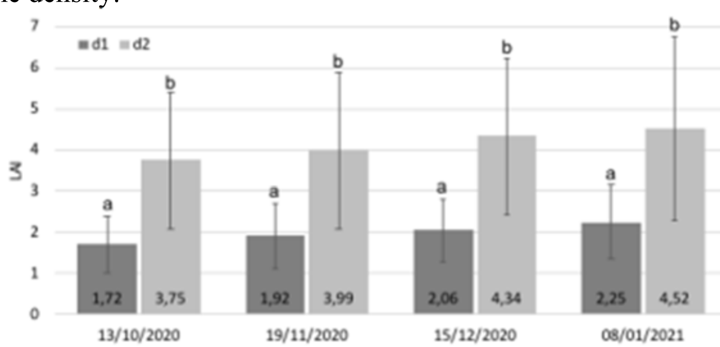

Figure 4: "Fischer" plot: comparison between LAI of densities d1 and d2 (re'a re'a variety) and evolution of the LAIs from the 13/10/20 to the 08/01/21. Results of Mann&Whitney test (sample < 30; p=0,05) are shown by letters a and b.

Vitrac *et al*. (6) observed that weeds had a very important influence on *Saccharum officinarum* fields and it could be interesting to renew this experimentation to evaluate the impact of weeds on a doubled density plot. It then could be shown that

improving LAI of *Saccharum officinarum* is able to influence weed development as well. However we didn't measure it from the tillering stage and Vitrac *et al*. showed that noble canes had a lower growth than modern varieties. During the boom stage, the sugarcane is very sensitive to weeds development, and organic agriculture do not allow the use of pesticides and farmers have to permanently tolerate an amount of weeds. They remove it mechanically and by hand (Vitrac et al., 2019a) which represent 80% of production costs (Vitrac et al., 2018b). Even though improving LAI might not reduced the production costs of *Saccharum officinarum* for farmers, it definitely allows to obtain more stalks at harvest, thus increasing their income.
This is what we observe with an approximate the biomass yield of 110 t/ha for d2 compared to 45 t/ha for d1 which is also linked to density (Figure 5). The measured biomass yield of d1 is approximately the same as Vitrac *et al*. found (50 t/ha). It indicates us the reliability of our data collected in our experiments.

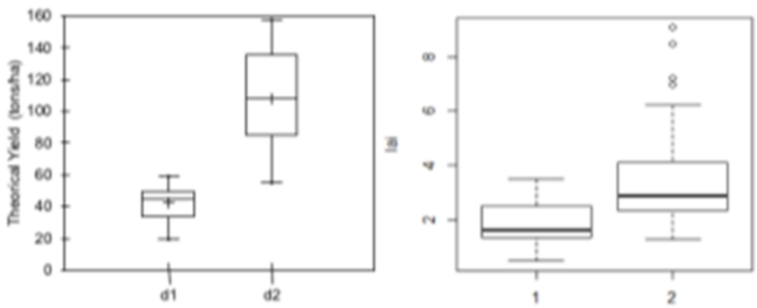

Figure 5: box plot of "Fischer" plot theorical yields (tons/ha, on the left) and global LAI (on the right) regarding densities d1(1) and d2(2) (re'a re'a variety).

Contrary to this result, Gomes da Silva *et al*. showed that there is no correlation between LAI and biomass yield contrary to our unusual conditions: *Saccharum officinarum* x organic agriculture. Their study is actually based on conventional agriculture and modern varieties. It shows us that organic agriculture with the use of *Saccharum officinarum* varieties (which has lower LAI, Figure 3) has to be regarded with different method and standards. This assumption is shown by the Figure 5: LAI is linked to density and correlated to the biomass yields. It is therefore useful to determine the LAI which can give a good idea of the density to apply for *Saccharum officinarum* fields.
The method we used is time consuming and is then not applicable for a farmer. Tournebize et al. (2007) proposed a method using photos and numeric data treatment to measure LAI without destroying any leaves or stems. It can indicate whether a density of plantation is adapted or not and also allow to follow cane stalk densities on long periods to see for example the influence of fertility on plant growth. Acquisition of satellite images is also a great tool to evaluate the density of a plot (Gate et al., 2019). It could be useful to evaluate at the scale of a field the observations made at a small scale, allowing to observe agronomic items such as fertility impact and how it can be correlated to density. For example, in some

organic agriculture context, fertilization has to be managed with organic fertilizer (contrary to inorganic) and it has different impacts on plant growth due to the composition of the fertilizer and to the period and method of application (Bokhtiar and Sakurai, 2005). Density could also influence morphologic parameters such as height, diameter, internodes length and tillering showing competition between plants and the limits of densifying a culture (Launay et al., 2020). LAI can help to indicate us theses correlations and this index has a very special interest for *Saccharum officinarum* organic fields.

Finally, we observed that To'a'eho variety had a theorical LAI of 6,69 (not significantly different from modern varieties, p=0,05) which is more than the average of modern varieties (5,18, Figure 3). This is a native inter generic hybrid of Polynesian *Saccharum officinarum x Miscanthus floridulus* (Vitrac et al., 20168a ; non published data). This variety is harvestable and could easily be used for weed control inside the rows. The reason is that even if their leaves are thin, the tillering is about 30 stems by plant allowing a very good soil covering from the first stages of growth. Therefore, an association with *Saccharum officinarum* re'are'a which show exactly the opposite could be very productive.

CONCLUSION

As *Saccharum officinarum* is no more cultivated for sugar production, few studies are available and high valuable rum production is still the only reason which justify its use. However, at the same time, new information allows us to think that several characteristics could be interesting to develop, especially under organic agriculture context. For example, useful varieties to manage weeds such as To'a'eho, a wild sugarcane is worth trying in sugarcane production as it is also easily harvestable.

The measured LAI in field indicated that determining the right density to improve *Saccharum officinarum* behavior in organic agriculture context is a reliable method and from our experiments it is correlated to biomass yield.

We then have the possibility to follow the LAI of this type of fields with numeric methods which give key agronomic indicators to continue to improve this high valuable agriculture for rum production.

Finally, under organic certified standards, doubling the density of *Saccharum officinarum* To re'are'a gave us good agronomic results regarding the biomass yields. This could be improved by the use of To 'a'eho intergeneric hybrid of *Saccharum officinarum x Miscanthus floridulus* inside the row to prevent the development of weeds.

REFERENCES

Fauconnier R. (1991). La canne à sucre /*Sugar cane*/. Maisonneuve & Larose, Paris, 165 p.

Kumawat P.D., Dahima N.U. (2016). Effect of Sugarcane (Saccharum officinarum L.) Varieties and Row Spacing on Growth, Yield and Quality of Sugarcane. Progressive Agriculture. Volume: 16, Issue: 1. doi: 10.5958/0976-4615.2016.00015.6

Poser C., Chabanne A., Martin J., Gueno J.M., Ribotte J.C., Tumoine L., Le Bras J., Christina M., Goebel F.R. (2018). In : ISSCT, p. 17-17. ISSCT Agricultural Engineering, Agronomy and Extension Workshop : "Farming for the future: improving productivity and ecological resilience in sugarcane production systems". 3, 2018-09-23/2018-09-28, Saint Gilles (Réunion).

Pouzet D., Lienhart B. (1998). Compte rendu d'enquête sur la distance de plantation des lignes de canne /*Survey report on the planting distance of cane lines*/. Saint-Denis : CIRAD-CA, 15 p.

Pouzet D., Martiné J. F., Lienhart B. (1999). Distance interligne de plantation et composantes du rendement de la canne à sucre : Premiers résultats des essais conduits en basse et haute altitude /*Planting interrow distance and components of sugarcane yield: First results of trials conducted at low and high altitudes*/. Saint-Denis: CIRAD-CA, 16 p.

Vitrac M., Martin J., Teai T., Shili-Touzi I., Goebel F. R. (2019a). Des cannes nobles tahitiennes cultivées en bio anéanties par le wedelia Sphagneticola trilobata : une mésaventure à surmonter /*Noble Tahitian canes grown organically destroyed by the wedelia Sphagneticola trilobata: a misadventure to overcome*/. In 24e Conférence du COLUMA, Journées internationales sur la lutte contre les mauvaises herbes. Végéphyl. Alfortville : Végéphyl, 11 p. Conférence du COLUMA : Journées internationales sur la lutte contre les mauvaises herbes. 24, Orléans, France, 3 Décembre 2019/5 Décembre 2019

Vitrac, M., Teai, T., Goebel, F. R., Shili-Touzi, I. (2019b). Noble sugarcanes and modern cultivars in Tahiti relative to organic rum production: description and key characteristics. AGROFOR International Journal, (4) 20-27. doi:10.7251/AGRENG1902020V

Vitrac M., Teai, T., Goebel, F. R. (2018a). Sugarcanes and the Saccharum genus in French Polynesia: historical and future potential uses. In: CIPAM 10 : 10ème Colloque International sur les Plantes Aromatiques et Médicinales et Cosmétopées. 19-23 Novembre 2018, Punaauia (French Polynesia).

Launay M., Constantin J., Deswarte J.C., Maunas L. (2020). Effets de la mise en place du peuplement sur le fonctionnement du couvert et la production végétale /*Effects of the establishment of the stand on the functioning of the cover and plant production*/. p151-176, In: Boiffin J., Laurent F., Richard G. (2020). Réussir l'implantation des cultures. Enjeux agroécologiques, itinéraires techniques. Éditions Quæ et Arvalis, Versailles et Paris, 440 p.

Vitrac M., Teai T., Goebel F. R., Shili-Touzi I. (2018b). Organic sugarcane cultivation in Tahiti. AGROFOR International Journal (3). 31-38. doi: 10.7251/AGRENG1803031V.

Hermann E. R., Câmara G. M. S. (1999). Um método simples para estimar a area foliar de cana de açucar /*A simple method to estimate sugarcane leaf area/.* Sociedade dos Técnicos Açucareiros e alcooleiros do Brasil, (17) 32-34.

Castro-Nava S., Huerta A. J., Plácido-de la Cruz J. M., Mireles-Rodríguez E. (2016). Leaf Growth and Canopy Development of Three Sugarcane Genotypes under High Temperature Rainfed Conditions in Northeastern Mexico.

International Journal of Agronomy. vol. 2016, Article ID 2561026, 7 pages. doi.org/10.1155/2016/2561026.

Gomes da Silva V. S., Wagner de Oliveira M., Albino Oliveira T. B., Campos Mantovanelli B., Cicero da Silva A., Ribeiro Soares A. N., Aprigio Clemente P. R. (2017). Leaf area of sugarcane varieties and their correlation with biomass productivity in three cylces. African Journal of Agricultural Research (12): 459-466, doi: 10.5897/AJAR2016.11817

Tournebize R., Bonhomme R., Pouzet D. (2007). Estimation de l'indice foliaire d'une culture de canne à sucre à l'aide de photographies hémisphériques faites in situ /*Estimation of the leaf area index of a sugar cane crop using hemispherical photographs taken in situ*/. Cah. Techn. INRA 2007 60, 29-36.

Gate P., Soenen B., Closset M., Benamou N., Poilvé H., Feuga M. (2019). La cartographie des parcelles agricoles et les services associés à Farmstar /*Agricultural plot mapping and services associated with Farmstar*/. Responsabilité & environnement (94): 61–65.

Bokhtiar S.M., Sakurai K. (2005). Effect of application of inorganic and organic fertilizers on growth, yield and quality of sugarcane. Sugar Tech (7): 33–37. doi.org/10.1007/BF02942415.