ISSN 0015-0886

Ministry of Agriculture

FIJI AGRICULTURAL JOURNAL

Volume 54
Issue No. 1
June 2014

Fiji Agricultural Journal

This journal is fully funded by the Ministry of Agriculture,
Government of the Republic of Fiji, to which we are all grateful.

ISSN 0015 - 0886

Fiji Agricultural Journal

Vol. 54, No. 1, 2014

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REVIEW

Opportunities for Benefiting from the System of Rice Intensification in Fiji and Pacific Island Countries

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1.0 INTRODUCTION

Increased food price volatility, global climate changes, and rising foreign trade imbalances caused by large-scale food imports have in recent years affected both the food security and the financial security of countries belonging to the African, Caribbean and Pacific Group of States (ACP). Many ACP countries have attempted to address these factors by adapting policies intended to increase their domestic rice production, and Fiji is no exception to this.

Since at least Independence, the Fijian government has recognized the need to increase domestic rice production to reduce the financial burden of its rice imports. Yet 44 years later, rice production in Fiji is lower than it was then, while population and per capita consumption of rice have steadily increased (Fig 1).

Previous attempts to increase rice production in Fiji have largely relied on conventional development strategies, such as large infrastructural investments, and the use of high-yielding varieties (HYV) and chemical fertilization. These approaches certainly have important roles to play, but they have limitations, and entail substantial costs as well. Any program to increase rice production must, therefore, do so in a manner that takes into full account local conditions, needs, constraints, and opportunities.

If done effectively, a well-designed program that increases domestic rice production can buffer Fiji and other ACP countries from market price fluctuations, can improve their foreign exchange position, and can contribute to greater national food security and political stability. If done poorly, increases in rice production can lead to increased competition for scarce agricultural land (thus hurting the production of other staple crops), increased dependence on imported agrochemical inputs, competition for valuable water resources, chemical contamination of freshwater and marine systems, and potential environmental damage to sensitive non-agricultural ecosystems like mangrove swamps.

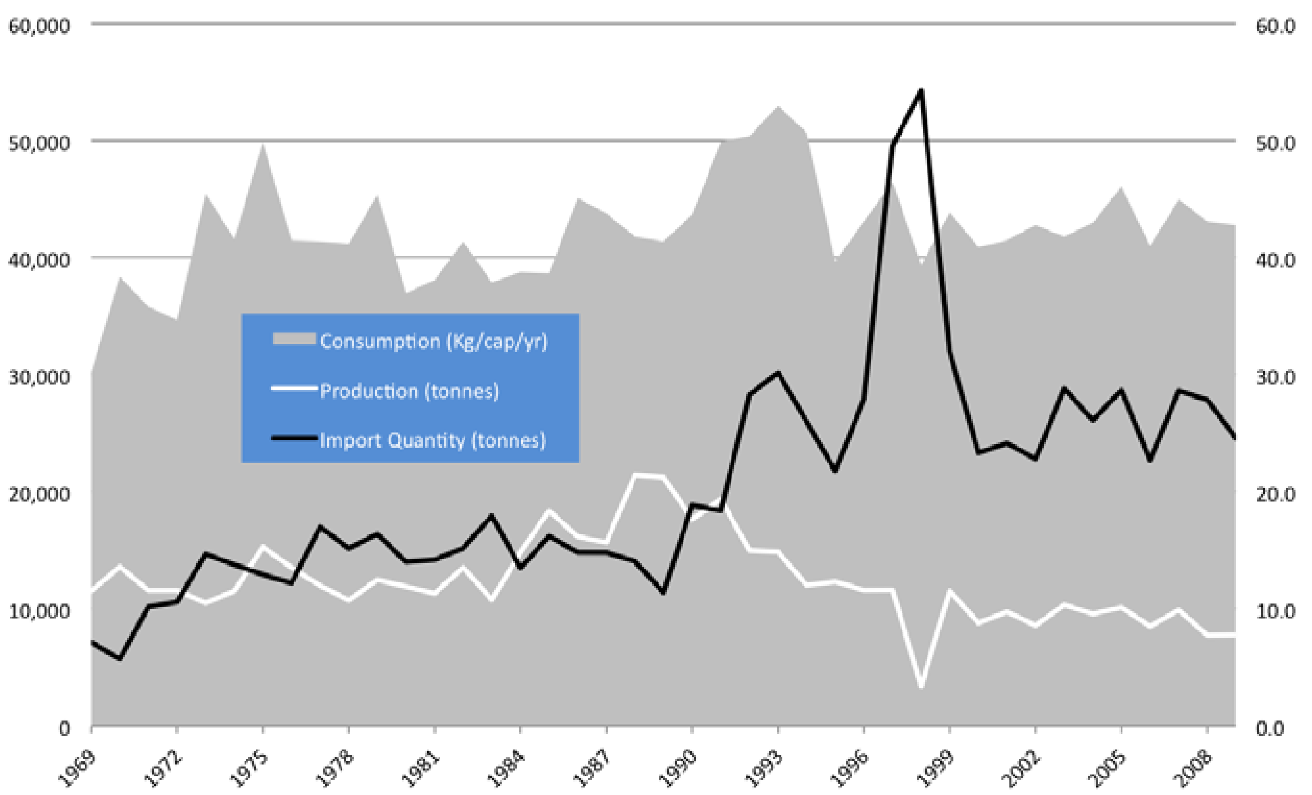

Figure 1. Rice Consumption, Production and Importation in Fiji, 1969-2009 (source: FAOStat)

Fortunately, some experience within the ACP community offers an advantageous strategy to improve the production of rice while reducing the potential for undesirable economic and ecological effects. The System of Rice Intensification (SRI), first developed in Madagascar, deserves attention as it has been tested and evaluated, and is being scaled up in a number of countries throughout Africa and the Caribbean, with interest starting to develop in the Pacific islands as well.

SRI is an agroecological method for producing rice that requires fewer agrochemical inputs and uses less seed and water, while producing more rice and buffering crops against the effects of climate change. This paper first presents a short summary of rice production in Fiji, followed by a description of the SRI methodology; then it presents opportunities for improving rice production in Fiji with SRI, and finally, suggests dialog points around which a national SRI strategy in Fiji could be developed.

2.0 THE RICE CONTEXT IN FIJI

While traditional root crops such as taro, cassava and yams have historically provided the bulk of carbohydrates for Fijian households, and sugarcane has been the most economically-important agricultural crop, rice nonetheless has a long history in Fiji, and it plays an increasingly important role today. Indian immigrants, who came to work in the sugarcane industry in the second half of the 19th century, brought both an appetite for rice and an ability to grow it, setting up Fiji's first rice fields in marginal lands alongside the sugarcane fields (Overton 1988).

Through the 20th century, rice continued to play a secondary role to sugar and other crops, but as sugar prices periodically fell, particularly in the 1930's and 1940's, the colonial government began promoting rice production in its own right — only to reverse course when sugar prices rose again in the 1950's (Overton 1988).

Starting in the late 1950's, rice production efforts began to be delinked from sugar prices, particularly with the closure of sugarcane production on the wet side of Viti Levu. Rice production accelerated throughout the rest of the 20th century, boosted by successive waves of post-Independence government initiatives to promote rice self-sufficiency through import substitution (Overton 1988).

Since Independence, plans to achieve rice self-sufficiency have made temporary gains, particularly in the mid-1980's, with adoption of an import-substitution policy. During this period, the government invested in constructing irrigation schemes, introducing new varieties, and improving extension services. More credit was provided to farmers, rice importation was limited, and for a brief period local rice production was able to meet as much as 75% of the domestic consumption.

Yet rice production has decreased since the 1990s due to the combined effects of multiple factors.[3] Withdrawal of government investment and subsidies has increased the costs of production for smallholder producers, who tend to have little capital available for investing in production and limited access to credit and technical support.

Extreme weather events have added to these difficulties, and labor costs have remained high due to shortages caused by emigration of the agricultural population. Such unfavorable conditions have forced many farmers to give up cultivating rice. Fiji's rice self-sufficiency has declined now to about 12%. The consumption and reliance on imported rice will probably further increase as the population grows.

Unfortunately, despite some promising results, these supportive measures were abandoned due to political unrest (Prasad and Narayan, 2005). Exacerbated by severe weather, the long-term trend has been toward decreased self-sufficiency (Fig 1), and indeed, 2010 and 2011 were the second and third lowest production years since before 1969, surpassed only by the low yields impacted by bad weather in 1997 (Fiji Bureau of Statistics 2013; FAOStat; OCHA 1998).

With decreasing yields, increasing energy and food costs, and steadily rising rice consumption, interest in rice import substitution has renewed in recent years. The government has made it a major priority to reduce rice import payments, which have been averaging FJD 40m in recent years (Oryza 2012).

[3] Data about Fiji rice production and import is shown in the following link: http://www.unapcaem.org/Activities%20Files/A1112sanya/fj.pdf

Fiji's rice sector is heterogeneous, both in terms of cropping systems and farmer profiles. Production is split among three agroecological systems: irrigated (20%), rainfed wetland (44%), and rainfed dryland (36%). Rainfed wetland rice, the largest system by area, has the potential for two cropping cycles per year in the wetter areas. Roughly 80% of the rice grown in these areas is traditional varieties (Puran 2011). Rainfed dryland rice is primarily intercropped with sugarcane, and grown only during the main cropping season (Puran 2011).

With a long legacy of Indo-Fijian farmers cultivating their own rice, there is a strong local attachment to traditional varieties of rice, largely due to eating preferences, grain quality, and adaptability to agronomic and economic conditions. As a result, farmers are very resistant to abandoning these varieties (Puran 2011). Roughly 85% of Fijian rice farmers cultivate rice in rainfed and/or upland conditions, typically without applications of fertilizer and pesticides. There is a general reluctance among farmers to spend money on such inputs and a general uncertainty about the amount and distribution of rainfall (Puran 2011).

Farm size in Fiji varies considerably between irrigated and rainfed production systems. Irrigated farms tend to be more mechanized, and larger in size (up to 1-2 ha), with farmers having better access to credit (Puran 2011). These larger, better-equipped farms are also most likely to adopt new technologies and to remain adopters, as their larger holdings enable them to experiment on small parcels, limiting their risk, until they are confident in the new approach being tested (Puran 2011).

Water security may also play a factor in decision-making, as farmers with irrigation are more likely than farmers in rainfed conditions to have confidence in the sufficient availability of water during their cropping season. Smallholder farmers with less than 1 ha (44% of the farming population) are typically subsistence in nature, and are far less likely to experiment with, adopt and continue using new technologies (Puran 2011). This has been in part due to farmers' lack of access to mechanization, but also to the deterrent effect of costs, such as for tractors, irrigation, bullocks, and other equipment (Puran 2011).

3.0 THE SRI METHODOLOGY — PRINCIPLES AND PRACTICES

Developed as an innovation with and for smallholding farmers in Madagascar, the beneficial effects of System of Rice Intensification (SRI) practices have been seen now in over 50 rice-cultivating countries in Asia, Africa and Latin America. The core principles of SRI include:

1. Undertake early, quick and healthy plant establishment;
2. Reduce competition among plants through wider spacing;
3. Improve soils with organic matter enrichment;
4. Enhance an aerobic soil environment for plant growth.

These principles work together synergistically to create phenotypic changes in the rice plants themselves, meaning that the plants express a more productive form and shape. Such plants develop more tillers and larger panicles than traditionally-grown paddy rice plants that are crowded together and grown in continuously flooded fields — as is common practice in many of the world's rice-producing areas.

SRI's four principles may need to be applied somewhat differently depending on local conditions, reflecting varying degrees of: control of water, availability of mechanization, soil health, favorable climate, labor availability, access to different rice varieties, etc. Therefore, the practices that support SRI's four core principles will vary — sometimes quite a bit—but the aim is always to maximize the defining feature of SRI: a synergistic change in plant phenotype that results in higher yields and to improve soil health through a reduction of inorganic inputs and conducive soil and water management. Positive feedback between roots and the canopy supports the growth and health of plants both below- and above-ground.

When grown with SRI management, rice plants develop longer, fuller root systems. These roots search more deeply and broadly in the soil profile for water and nutrients, and due to significantly reduced competition between plants, they are able to support more robust, healthier and stronger above-ground shoot systems. The plants then are better able to resist stress from drought (due to deeper roots and the better moisture-retention properties of increased organic matter in the soil), severe wind and rain (due to increased root anchoring and stronger shoots), and insect/disease attacks (due to better air movement, more robust natural defense systems as a result of healthier plants and reduced competition, and greater soil biological diversity, which helps keep pathogenic organisms in check). With wider spacing, plant leaf angles are more open, allowing for greater light interception and increasing photosynthetic potential (Thakur *et al.* 2010).

In sum, these healthier plants produce larger panicles, with larger grains, and have better grain filling than the same varieties do when grown with conventional practices. Further, SRI management also commonly reduces the length of the cropping cycle, typically by 1-2 weeks, with higher yield. All of this is done using substantially less seed (reduced by 80-90%), with greater soil biological health, and often with much less water (reduced by 20-25% overall and with irrigation reduced by about 35%) (Jagannath *et al*. 2013).

With these changes in mind, SRI practices can be combined in any number of ways, seeking to follow the core principles of SRI and to maximize the beneficial impacts that can result. Farmers assume an important role as researchers and evaluators, testing out different practices and combinations of practices to adapt the four SRI principles to their specific conditions, and to maximize the beneficial effects of the phenotypic change that can result from SRI management.

Where rainfall, groundwater, and/or irrigation water is consistent or reliable, farmers typically start nurseries (instead of direct seeding their fields), and transplant seedlings into the fields at a very young age (when each plant has just two leaves). These seedlings are placed only one per hill, in a wide square grid with a spacing of 25cm or more between plants. (The optimum spacing depends upon the level of soil fertility and the variety used).

Where inconsistent rainfall, lack of irrigation or unreliable groundwater render transplanting more risky, farmers often direct-seed their fields, using two or possibly more seedlings per hill, while still respecting the wide grid spacing.[4] When these direct-seeded plants reach the two-leaf stage, they can be thinned to one per hill. In some circumstances, farmers may find that the added yield boost achieved by thinning out the hills to just one plant may be offset by the higher labor cost of thinning, in which case they may leave two plants per hill.

[4] See the following paragraph about reasons for reducing the plant spacing below the recommended 25 cm.

Similarly, farmers with poor soils who are using upright varieties that are less prone to tillering may find that their plants are unable to make full use of the recommended plant spacing of 25 cm or more, and so they may reduce this spacing to 20 cm or so. However, most farmers find that their plant varieties and soil conditions combine to readily allow their plants to fill a spacing of 25 cm, and this is the recommended spacing to begin with when evaluating SRI.

Those farmers who have rich soils may find that they can increase their plant spacing to 30 or even 40 cm, thereby further increasing yields by more fully taking advantage of the beneficial changes induced by SRI management. Through these various adaptations, farmers adjust their practices to support the first and second principles of SRI: favor early, quick and healthy plant establishment; and reduce competition among plants.

For farmers accustomed to fertilizing their soils and crops with organic matter (OM), SRI involves little transition in soil fertility management. However, in many ACP communities this is not the norm. While all farmers can incorporate OM matter into their fertilization regime, the kinds, quantities and methods will vary greatly, and can include manure (of differing origins), compost, crop residues/stubble, etc. Farmers practicing SRI are encouraged to experiment freely with the frequency, amount and types of OM applications to see which combination works best with SRI management and provides the greatest soil health benefits.

Where water is both reliable and easily controllable — both for watering and draining the fields — alternate wetting and drying (AWD) is typically practiced instead of continuous irrigation. Without flooding as a method for weed control, mechanical weeding or heavy mulching with organic matter (crop residues, for example) is typically practiced to suppress weeds.

Where water is unreliable and/or not easily controlled, field leveling, bunding, and generous applications of organic matter are often used to increase moisture retention (where risk of drought is a concern) and/or facilitate drainage and soil aeration through biological activity (earthworm tunneling, for example). Through these various adaptations, farmers are able to modify their practices to support the third and fourth principles of SRI: improve soils with organic matter; and practice aerobic soil management.

With these benefits coming largely from shifts in management practices and not from increased use of inputs and expensive infrastructure, it is easy to see why SRI has spread quickly in many developing countries, and the number of smallholder farmers utilizing many or all of SRI's methods is now approaching 10 million worldwide.[5]

SRI use has become widespread in some of Asia's largest rice-producing countries, and has gotten started in dozens of other countries in the past 15 years. Governments in China, India, Indonesia, Vietnam and Cambodia, where two-thirds of the world's rice is produced, are now giving support to SRI extension. However, it is still a new concept for most people in the Pacific islands and in the Caribbean region, and to farmers in many African countries (Fig 2).

Figure 2. Bourema, the first farmer in Burkina Faso to use SRI methods, getting a 7 ton/ha yield, showing the root growth and tillers on one of his SRI plants, which was grown from a single seed. (Picture: Tim Krupnik).

Taking an ACP perspective, these countries share many similarities with each other regarding climatic conditions and their agricultural production opportunities — year-round warm and moist climates, and small-scale polycultural farming systems. Moreover, they are facing some

[5] A report summarizing a global survey of SRI adoption by Dr. Norman Uphoff and Dr. Erika Styger, both of Cornell University's SRI-Rice Center, is currently in the final review process and will be published shortly on the SRI-Rice website, at http://www.sririce.org.

common problems, which include having to adapt to climate change with scarce resources, persistent food insecurity or lack of self-sufficiency, pressure on vulnerable natural resource bases, limited access to the means of production for agriculture, economic trade imbalances, and the need for a more sustainable agriculture.

4.0 OPPORTUNITIES FOR IMPROVING RICE PRODUCTION IN FIJI WITH SRI

Conventional agricultural development paradigms are often characterized by several principles which can either limit their adoptability — and therefore success — or can have negative attributes that call into question their environmental impact and their long-term sustainability. SRI offers many important opportunities for increasing rice production in Fiji in a manner that is appropriate to local conditions and offers potential for greater long-term sustainability.

With the many challenges facing agriculture, our environment, and our economies, it is becoming increasingly critical to establish forms of sustainable agriculture that can both improve people's living standards and protect ecosystems and natural resources. As an intensification strategy — i.e., growing more food on the same area of land rather than expanding land area to increase production — the SRI approach can avoid competition with sugar cane and Fiji's other staple and cash crops, and relieve pressure on the country's fragile natural ecosystems. The international agricultural development community has increasingly shifted towards promotion of intensification strategies in recent years, recognizing the negative impacts of extensification approaches — ones that increase the area under production.

Furthermore, proper use of organic matter as a primary fertilizer — which SRI promotes — can help prevent environmental contamination and related problems, such as eutrophication of water bodies, which are often associated with chemical fertilizer use and which are a serious threat for countries like Fiji, where aquatic resources are a fundamental economic, cultural, social and ecological cornerstone of society. Without a healthy aquatic environment, Fiji's fisheries, tourism industry, unique wildlife, and cultural heritage would be at risk.

Conventional rice production is also among the largest consumers of fresh water on the planet. This 'thirstiness' of current rice production puts Fijian rice farmers at odds with competing demands on the country's water resources, including residential, tourist, industry and other agricultural uses. SRI dramatically increases water use efficiency in irrigated rice, thereby reducing the competition for this precious resource.

Global climate changes are of paramount concern around the world, but particularly in places like Fiji. Its agriculture can expect to be particularly hard-hit, and resource-poor farmers like many of Fiji's traditional rice growers, will face increased hardship on top of what they are already confronting. As mentioned above, farmers using SRI methods typically see increased crop resiliency to extreme weather such as drought, variable rainfall and high winds, and to pest and disease attacks. SRI can also shorten the cropping cycle, by as much as two weeks, thereby reducing yield loss associated with rainy seasons that start too late or end prematurely.

As an archipelago, the vast majority of chemical inputs must be imported to Fiji, and these are likely to become more expensive with the probable rise in prices for fossil fuels (Puran 2011) — which are used in both the fabrication and transport of these inputs. This reality makes development strategies that rely heavily on chemical inputs potentially unsuitable. Because SRI focuses on utilizing organic materials as a primary means of fertilization, it can reduce the financial burden of these imports, and instead shift the focus to developing and enhancing natural soil fertility cycling and making the most of local resources.

Another component of many conventional development strategies is to promote HYVs, many of which require relatively large applications of chemical fertilizers in order to boost yields. In addition to the just-mentioned cost issue associated with chemical fertilizers, such strategies have proven to be of limited benefit in Fiji, particularly with smallholder, subsistence farmers. Modern HYVs do not possess many of the non-agronomic traits that farming families value, such as threshing, cooking, and flavor qualities. As a result, subsistence Fijian farmers have historically been resistant to development efforts that focus on replacing traditional varieties with new HYVs.

Because SRI works with practically any variety of rice (although some varieties of rice respond more positively to SRI than others), it can help smallholder farmers raise their yields without abandoning their traditional varieties. This creates a win-win situation, as farmers can increase yields with less cost while still benefiting from the desired traits their traditional varieties possess.

Often conventional strategies for increasing rice production depend heavily on large infrastructural projects, which in the context of Fiji can either displace or marginalize smallholder farmers, or are subject to a high degree of uncertainty in terms of their future sustainability. In contrast, SRI, which was developed with and has spread primarily among smallholder farmers, requires no expensive and difficult-to-maintain infrastructural improvements. Where irrigation schemes are present or are being developed in Fiji, SRI can help farmers decrease their water consumption for irrigated rice production by around 30%, while increasing yields by 50% or more, thereby making these large-scale investments more efficient.

5.0 IDEAS AND SUGGESTIONS FOR INTRODUCING SRI IN FIJI

Fortunately, in Fiji and the other Pacific countries, national governments have in many cases recognized the need for building more sustainable agricultural systems, and may be willing to adopt new approaches, which is an advantage and opportunity for establishing SRI. For example, the Special Ministerial Conference on Agriculture in Small Island Developing States already in 1999 proposed the goal of a "more intensified, diversified and sustainable agriculture,"[6] and the Pacific Islands Forum Secretariat (PIFS) endorsed the Regional Programme for Food Security in 2002.[7]

The Solomon Islands government in 2010 issued a white paper on 'National Rice Sector Policy (2010-2015)' that endorsed the introduction of the System of Rice Intensification.[8] And that same year, the Ministry of Agriculture and Livestock invited an Indonesian SRI farmer/trainer, Ms. Miyatty Jannah from East Java, to provide six weeks of hands-on training for farmers and extension personnel in SRI methods (Fig. 3).

Figure 3. Miyatty Jannah on her farm in Ngawi district, East Java, Indonesia, showing the difference between an SRI rice plant (on left) and several conventionally-grown rice plants of same variety (on right), contrasting root volume as well as tillering. (Photo: Shuichi Sato).

This official support for sustainable agricultural development is important, and should be utilized to its fullest. Collaborative planning of an SRI introduction, evaluation, and potential scaling-up involving government ministries, extension services, the private sector, NGOs, and donor agencies can help create multi-stakeholder buy-in. This support is important for ensuring that all partners have some level of shared understanding about the needs for such an initiative, the potential benefits that it can bring if done right, and their roles in making this happen.

Additionally, as SRI differs from standard rice production methods, a common understanding of what SRI is and how to implement and adapt it is extremely important. Such an understanding can be developed through national workshops or training programs. If possible, exchange visits to other countries in the broader region that are practicing SRI should be encouraged, to allow for key stakeholders to see it for themselves in advance of trying it out on

[6] The full document of the conference is available on FAO's website: http://www.fao.org/docrep/meeting/x1296e.htm

[7] See report from UN Department of Economic and Social Affairs – Division for Sustainable Development: http://www.un.org/esa/agenda21/natlinfo/countr/fiji/agriculture.pdf

[8] See: http://sri.ciifad.cornell.edu/countries/solomonislands/SI_Natl_Rice_Sector_Policy2010to2015.pdf

[9] A continuously updated list of activities and projects in over 50 countries is available at the SRI-Rice website, at: http://sri.cals.cornell.edu/countries/index.html

the ground in Fiji.[9]
Once a more nuanced understanding of SRI is developed, policy makers should consider reviewing the impacts of current government policies on the promotion or disincentivization of agricultural production strategies that are ecologically appropriate, and then make any necessary changes to ensure a favorable climate for sustainable intensification.

Once SRI has been introduced, and farmers and technicians have gained some experience and practice with the methodology, exchange visits to other countries with SRI experience can help further develop adaptation strategies and learn from their successes and challenges. The international NGO Oxfam has been doing such exchanges, having recently brought farmers from Haiti[10] to learn from the successful introduction and scaling up of SRI in Vietnam (where an estimated 1.3 million farmers had adopted SRI by December 2012[11]),[12] and it has just recently introduced SRI to Timor Leste.[13]

Intraregional sharing shouldn't be limited to exchange visits, however, and stakeholders in Fiji and other the Pacific Island countries should actively seek to form connection with existing networks of practitioners in other parts of the world. Such networks are actively engaged in identifying and disseminating SRI innovations, including adaptations for non-irrigated production systems, and development of new mechanical weeders, transplanters, etc.[14] By connecting future SRI practitioners and technicians in Fiji with the broader world, Fiji can both learn from the experience of millions of other farmers and can begin to contribute their own findings to a broader audience.

Returning back to a local level, as mentioned above, the success of SRI in Fiji will to a large degree depend on the ability of various stakeholders within the country to effectively collaborate. Beyond just involving actors on the policy, planning and project management levels, farmers as well will have to be actively engaged in each step of the process.

This paper has described how SRI radically changes the rice production process, and how this renders the mental aspect of changing deeply-ingrained habits one of the most important and challenging components of adopting SRI. Because of this reality, farmers need to be actively engaged as collaborators. Furthermore, because SRI requires adaptations for different rice production systems and local conditions, a thorough understanding of the SRI principles is needed so that farmers can make informed decisions about how to apply SRI principles. If farmers are simply told to carry out a certain set of practices without their understanding the rationale behind these, it is likely that they will be less open-minded about the new methodology (and thus less prepared to make the important mental shift in understanding SRI), and ultimately less effective in adapting SRI to their local conditions.

Furthermore, without a thorough understand of the whole system of SRI and the reasons behind the modifications of practices, farmers will not be confident enough about what they are doing and will tend to revert back to their earlier experience and traditions when managing their fields, which means failing to follow all the steps that should be taken. In examples from other ACP countries, it has been seen that partial and careless implementation can lead to SRI not working properly, with the farmers not realizing the potential benefits from SRI, and potentially growing discouraged and becoming reluctant to try it again in the future.

Hands-on training combined with detailed explanation of the principles and related practices of SRI can help prevent this scenario from happening. During the growing season, farmers' work should be supervised on a regular basis, and demonstration plots should be collaboratively planned and managed to promote farmer buy-in, which will create ownership over the trials and a personal investment in the outcomes.

To ensure that these conditions are well met, farmers' organizations should be involved from the beginning and play a key role in any workshops, meetings and trainings to plan a national implementation strategy — no matter how large or limited the strategy ends up being. Any such strategy should take into account both the wide variety of rice production systems in Fiji, and the varying socio-economic backgrounds of different groups of rice producers. Key target zones could be identified throughout the country, and early evaluations could be planned to cover some of the most significant and representative rice production zones in the country,

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[10] Information on this is available at: https://buddhistglobalrelief.wordpress.com/tag/oxfam/

[11] Information on this is available at: http://www.oxfamamerica.org/explore/stories/13-million-rice-farmers-now-using-innovative-growing-methods-in-vietnam/

[12] Information on this exchange is available at: http://www.oxfamblogs.org/vietnam/2013/05/31/destination-vietnam-the-return and http://www.oxfamamerica.org/explore/stories/lessons-learned-growing-rice-in-haiti-and-vietnam

[13] An article on this is available at: http://www.oxfam.org.nz/blogs/2014/06/10/harvest-hope-east-timor Efforts by GIZ to introduce SRI into Timor Leste have been supported by the Indonesian Association for SRI (Ina-SRI), a voluntary network whose members have visited that country or hosted visitors from Timor Leste to help get SRI started there. An NGO promoting SRI in Indonesia known as NOSC (http://www.slideshare.net/SRI.CORNELL/1301-presentasi-nosc-sri-organik) has facilitated SRI training in Solomon Islands, and both Ina-SRI and NOSC can share Indonesian SRI experience with other island nations in the Pacific region.

[14] A thorough listing of networks by region and country is available at: http://sri.ciifad.cornell.edu/listservs/index.html

ensuring a coordinated approach to introducing SRI and beginning the adaptation process.

A successful SRI adaptation process will require the kinds of collaboration described above between farmers, researchers, extension agents, and technicians, as well as mechanisms for identifying and sharing innovations around the country. The form that these take will depend on local resources and on what roles partners and organizations decide to take. Farmers should also be encouraged to experiment, and in collaboration with researchers and extension agents should keep detailed notes of their practices and modifications to these.

Initial SRI trials do not require special tools or infrastructure to get started, and in fact, trials should start with the existing tools that farmers have and are familiar with using. By starting small, these trials can introduce SRI principles and can point to the most important changes that will need to be addressed in order to scale up SRI.
Supplied with results from these first trials, projects and farmers can work together to identify and source any needed infrastructure, equipment, and materials to make SRI methods easier to use and more efficient. If farmers start small with well-organized initial trials, the willpower to source appropriate technology can stem from initial positive experiences. In any case, initial trials should be small, carefully-planned, and aimed at reducing any potential for obstacles.

Where applicable — particularly in lowland settings — functional irrigation systems will be helpful as SRI responds well to careful water control, and this will also benefit other crops grown in the same region. For small-scale farmers with little access to irrigation resources, simple methods such as bunding and leveling their fields, adding organic matter, and digging small drainage and irrigation canals can increase their water control and moisture retention in the soil. For upland areas, farmers can use these same methods, with a special focus on good field-leveling to decrease surface runoff and increase water capture, bunding to trap rainfall, and organic matter to increase the soil's moisture retention.

Weeding can be a burden, but will not be too difficult if it is done by a mechanical weeder. Mechanical push-weeders are already available in many countries, and motorized weeders are in the developmental stage.[15, 16] Government agencies and organizations can loan or lend weeders to communities for farmers to share and provide information about how to maintain and fix the weeders. If some weeder designs are sourced from outside Fiji, copies of these can then be fabricated locally as the designs are typically fairly simple and not patented, so manufacturers and blacksmiths should compete in terms of quality, price, and suitability. Regardless of the availability of specially-designed weeders, farmers can use whatever tools they are already familiar with using to weed their crops, and with initial positive experiences sources can be identified for weeders that can enable increasingly larger trials and more efficient labor practices.

What constitutes a good weeder for SRI depends heavily on local conditions (including soil, climate, labor availability, material availability, etc.), farmer preferences and customs, and the rice production system (rainfed, irrigated, etc.). Weeders used for other purposes can be adapted for SRI, and rice farmers around the world have been creative in adapting even non-weeder tools such as brooms with success. Experimentation, creativity, and networking are all key to finding appropriate and successful ways to increase weeding efficiency and efficacy.

As mentioned in the previous section, SRI allows farmers to increase production with their traditional varieties, but farmers should nevertheless be presented with choices, and encouraged to do SRI trials both with traditional varieties and newer high-yielding varieties. A robust dialog with farmers coupled with open access to a large number of varieties can increase farmer's access to and awareness of a multiplicity of options, some of which may serve their purposes better than traditional varieties while also increasing yields. It should be noted as well that while all varieties respond favorably to SRI management practices, some varieties respond more strongly than others, reinforcing the need for experimentation and access to an increased number of varieties.

Given the very different realities in Fiji facing smallholder rainfed farmers and their better-resourced irrigated farming counterparts, there will likely need to be different approaches used in introducing SRI within each group. Careful attention should be placed on identifying potential opportunities and constraints that SRI may present for each group. As mentioned above, trials should be conducted with full participation and involvement of farmers in both settings, and be representative of the conditions that farmers are familiar with.

Besides focusing on SRI practices, as mentioned above, other initiatives aiming at sustainability will be important too, especially holistic farming system

[15] More information about various kind of weeders is available at: http://sri.ciifad.cornell.edu/countries/india/extmats/SRIWeeder-Manual06.pdf
[16] Interested readers are encouraged to join the SRI Equipment Innovators Facebook group to connect with SRI practitioners around the world in a discussion about the design, development, fabrication, adaptation and distribution of mechanical and motorized weeders: https://www.facebook.com/groups/SRI.innovators/

management and the reuse and recycling of materials. To be specific, knowledge of integrated pest and weed management, and making compost with farm waste are important initiatives for agricultural improvement, and not just for SRI. In this sense, SRI is an excellent avenue for introducing a broader set of sustainable land management techniques. Because farmers can immediately see a big difference in their plants' health and in their yields, there is a direct feedback loop that encourages further adoption of these beneficial practices.

Last but not least, multiple trials need to be carried out in different locations to assess the feasibility of SRI and the best adaptations, and to find out the most suitable combinations of plant spacing, rice variety, planting time, and weed suppression methods to suit the local condition. As these conditions vary, so will the optimizing combinations of practices.

Evaluation of the trials should not be limited just to yield data, but should also include environmental impacts, farmers' perceptions, and socioeconomic effects. The goal is to create a set of methods that can best benefit the farmers, the local agricultural system, and the natural environment. In short, Fiji has advantages and good opportunities to adopt SRI, but much preparation is also needed to ensure that the process will be smooth and that the outcomes will be beneficial for farmers, the natural ecosystems, and the country as a whole.

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REVIEW

Neem for Sustainable Pest Management and Environmental Conservation

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ABSTRACT

To be sustainable, agricultural processes, including pest and vector management must be efficient (effective and economically rewarding), ecologically sound (for long-term stability), equitable (in providing social justice), and ethical (in respecting both future generations and other species). Basic and applied research conducted over the past three decades have shown that the use of natural and enriched neem (*Azadirachta indica*) products and more than 100 bioactive compounds can provide a key component in ensuring sustainable integrated pest and vector management. Unlike toxic synthetic insecticides, neem materials do not kill the pest, but incapacitate or neutralize it via cumulative behavioral, physiological, and cytological effects. In spite of high selectivity, neem materials affect more than 500 species of insect pests, phytophagous mites, and mites and ticks affecting man and animals, parasitic protozoans, noxious molluscs, plant parasitic nematodes, pathogenic fungi, and harmful bacteria and fungi. Results of large-scale field trials have illustrated the value of neem-based pest management for enhancing crop productivity. Neem is useful as windbreaks and in areas of low rainfall and high wind speed, it can protect crop from desiccation. Neem trees are being planted on a large scale in southern China and Brazil. It has also been grown in many other countries. Neem has much to offer in solving agricultural and public health problems, especially in rural areas. Increased awareness of the potential of neem tree would go a long way in promoting its acceptance for pest management and improvement of plant animal, human, and environmental health.

Key words: Neem, *Azadirachta indica.*

1.0 INTRODUCTION

The global population is now 7.3 billion. Providing adequate food entitlements, safeguarding public health, meeting fuel and firewood needs, and at the same time preventing deforestation and conserving the environment, and slowing down the population growth will be daunting challenges in the coming decades. Although "green revolution technologies" have more than doubled the yield potential of cereals, especially rice and wheat in India, these high input production systems requiring large quantities of fertilizers, pesticides, irrigation, and machines disregard the ecological integrity of land, forests, and water resources, endanger the flora and fauna, and cannot be sustained over generations. Future food security and economic development would depend on improving the productivity of biophysical resources through the application of sustainable production methods, by improving tolerance of crops to adverse environmental conditions, and by reducing crop and post-harvest losses caused by pests and diseases. Appropriate technologies, which do not assault the nature, would have key roles to play in ensuring food security, in improving public and animal health, and in rehabilitating the environment to safeguard the wellbeing of the posterity. Instead of striving for more "green revolutions" with emphasis on miracle seeds, hard-hitting synthetic and engineered pesticides, and increased use of fertilizers, the future must look to natural ways and processes for augmenting agricultural productivity. In fact, all development efforts and activities, including pest management, should be within well-defined ecological rules rather than within narrow economic gains. Sustainable agricultural systems must be efficient (i.e. effective and economically rewarding) and ecologically sound for long-term food sufficiency, equitable in providing social justice, ethical in respecting both future generations and other species, and lead to employment and income-generating opportunities. For India and other countries, the use of neem may provide a key component in more sustainable agricultural systems, including pest and nutrient management, animal health, human health, and environmental conservation.

1.1 *Why Neem?*

Neem, a member of the Meliaceae family, is a botanical cousin of mahogany. According to a report of an ad hoc panel of the Board on Science and Technology for International Development, "this plant may usher in a new era in pest control, provide millions with inexpensive medicines, cut down the rate of human population growth and even reduce erosion, deforestation, and the excessive temperature of an overheated globe" (National Research Council 1992). Neem's other descriptions, such as "nature's bitter boon," "nature's gift to mankind," "the tree for many an occasion," "the tree that purifies," "the wonder tree," "the tree of the 21st century, and "a tree for solving global problems," are recognition of its versatility. Its botanic name, Azadirachta indica, derived from Farsi, "azad darakht-i-hindi" literally means the "free or noble tree of India," suggesting that it is literally free from pest and disease problems and is benign to the environment. Neem's Sanskritized name "Arishtha" means the reliever of sickness. In East African Kiswahili language, neem is known as "Mwarubaini," meaning the reliever of 40 disorders.

Neem is native to Myanmar and the arid regions of the Indian sub-continent, where it has almost been semi-domesticated. During the last century, neem was introduced in arid zones of Africa. Today, it is grown in many Asian countries, in tropical regions of the New World, in several Caribbean and in some Mediterranean countries. During the past three decades, neem was introduced and planted on a large scale in Australia, in the Philippines, and also in the Plains of Arafat near Meccah in Saudi Arabia, regions ecologically highly diverse. Over the past decade, more than 25 million neem trees have been grown in southern China, particularly in Yunnan province. In all these regions, the tree is thriving - a testimony to its hardiness and adaptability. Neem, however, is unsuited to growing in cooler and mountainous areas (>1000 masl).

Neem is an evergreen, tall, fast-growing tree, which can reach a height of 25 m and 2.5 m in girth. It has an attractive crown of deep-green foliage (which can spread 10 m across) and masses of honey scented flowers. The tree thrives even on nutrient-poor dry soil. It tolerates high to very high temperatures, low rainfall, long spells of drought, and salinity. It is propagated by seed, 9 to 12 month-old seedlings transplant well. Birds and bats disperse the seed. Fruiting begins in 3 to 5 years. In the Indian sub-continent, neem flowers from January through April and fruits mature from May to August. In coastal Kenya, fruiting occurs in March and April; some off types also fruit in November or December. The fruit is about 2 cm long, and when ripe, has a yellow fleshy pericarp, a white hard shell, and a brown, oil-rich seed kernel. Fruit yields range from 30 to 100 kg per tree, depending on rainfall, insolation, soil type, and neem ecotype or genotype. Fifty kg of fresh fruit yields 30 kg of seed, which gives 6 kg of oil and 24 kg of seed cake. Seed viability ranges from 6 to 8 weeks, but thoroughly cleaned and properly dried and cooled seeds remain viable up to 6 months. Propagation by stumps and stem cuttings is also practiced. Plantlets, produced by tissue culturing, have also been used for propagation with partial successes.

Neem is bitter in taste. The bitterness is due to the presence of an array of complex compounds called "triterpenes" or more specifically "limonoids." More than 100 unique bioactive compounds have been isolated from various parts of the neem tree; still more are being isolated. This formidable array of highly bio-active compounds makes neem a unique plant with potential applications in agriculture, animal care, public health, and for regulating even human fertility. The limonoids in neem belong to nine basic structure groups: azadirone (from oil), amoorastatin (from fresh leaves, vepinin (from seed oil), vilasinin (from green leaves), gedunin (from seed oil and bark), nimbin (from leaves and seed), nimbolin (from kernel), and salannin (from leaves and seed), and the aza group (from neem seed). Azadirahtin and its analogs have fascinated researchers for the past 40 years because of phagorepellency, growth inhibition, and chemosterilizing effects on insect pests (Saxena 1989; Schmutterer 1990, 2002). The azadirachtin content in neem could vary considerably due to edaphic, climatic, or genotypic differences.

2.0 NEEM FOR ECO-FRIENDLY SUSTAINABLE PEST MANAGEMENT

2.1 *Crop Pests*

Pest control as practiced today in most developing countries relies mainly on the use of imported pesticides. This dependence has to be reduced. Although pesticides are generally profitable on direct crop return bases, their use often leads to the contamination of terrestrial and aquatic environments, damage to beneficial insects and wild biota, accidental poisoning of humans and livestock, and the twin problem of pest resistance and resurgence. More than 500 arthropod pest species have become resistant to one or more insecticides. Resistance of the cotton boll worm in India and Pakistan, of the Colorado potato beetle in the USA to all available insecticides, and of the diamondback moth to all classes of insecticides, including *Bacillus thuringiensis* (Bt), in Hawaii, Malaysia, the Philippines, Taiwan, and Thailand, illustrate the complexity of the problem. Shifts in pest status – from minor to major, and resurgence of pests, such as whiteflies caused by direct or indirect destruction of pests' natural enemies are other unwelcome developments associated with pesticide use. A World Health Organization and United Nations Environment Program report estimated that there are 1 million human pesticide poisonings each year in the world, with about 20,000 deaths, mostly in developing countries. The problem is rendered even more difficult because few, if any, new compounds are coming to replace old insecticides. The cost of developing and registering new pesticides is staggering: almost US$60 million, and pesticide manufacturers are unwilling to risk investment on products whose market life could be shortened by development of pest resistance.

For ecologically sound, equitable, and ethical pest management, there is need for control agents that are pest specific, nontoxic to humans and other biota, biodegradable, less prone to pest resistance and resurgence, and relatively less expensive. Among various options, neem has been identified as a source of environmentally "soft" natural pesticides.

Neem has had a long history of use primarily against household and storage pests and to some extent against crop pests in the Indian sub-continent. As early as 1930, neem cake was applied to rice- and sugarcane fields against stem borers and white ants. Early observations that swarming locusts did not attack neem leaves have been confirmed in laboratory studies and attributed to neem's antifeedant activity against locusts.

The pest control potential of neem in developing countries, however, remained largely untapped due to the advent of broad-spectrum synthetic insecticides. Also, publicity given to slogans such as "the only good bug is a dead bug" and identifying traditional uses of neem as backward, gradually weaned people away from using neem. It is only in the past two decades that the pest control potential of neem has been appreciated. Though subtle, neem's effects such as repellence, feeding

Table 1. Comparative rice tungro virus (RTV) control, grain yield, and net gain in rice fields sprayed with neem oil-custard-apple oil (NO-CAO) mixture or an insecticide (Abdul Kareem *et al.* 1987)[1]

Treatment	RTV (%)	Yield (t/ha)	Value of yield (US$)	Cost of treatment (US$)	Net gain (value of yield less cost of treatment)
			Jan-Apr 1984		
NO:CAO	5a	6.1a	1068	44	1024
BPMC	4a	6.1a	1068	125	943
Control	7a	5.6a	980	12	968
			Jun-Oct 1984		
NO-CAO	4a	5.1a	892	44	848
BPMC	6ab	4.7a	822	125	697
Control	9b	4.6a	805	12	793
			Nov 1984-Mar 1985		
NO-CAO	29a	3.1a	542	44	498
BPMC	56b	2.5b	438	125	313
Control	52b	2.3b	402	12	390

[1]Averages of 4 replications per cropping season. Cost of rice = $ 0.175/kg. NO-CAO mixture and BPMC insecticide were applied 8 times during each cropping season. Means followed by a common letter are not significantly different at the 5 per cent level by Duncan's Multiple Range Test. Cost of treatment included labor and materials. Control treatment cost included labor (US$10) and 8 pieces of DC batteries (US$ 2) for applying 1.6% Teepol-water solution (emulsifier) using an ultra-low volume applicator.

and oviposition deterrence, growth inhibition, mating disruption, chemo-sterilization, etc. are now considered far more desirable than a quick knock-down in integrated pest management programs as they reduce the risk of exposing pests' natural enemies to poisoned food or starvation. In spite of high selectivity, neem derivatives affect ca. 400 to 500 species of insect pests belonging to different orders (Schmutterer and Singh 2002), one species of ostracod, several species of mites, and nematodes, and even noxious snails and fungi, including aflatoxin-producing Aspergillus spp.

Results of field trials in some major food crops in tropical countries illustrated the value of neem-based pest management for enhancing agricultural productivity in Asia and Africa.

Rice. The efficacy of neem derivatives against major pests of rice and virus diseases transmitted by them and increases in yield has been reviewed by Saxena (1989). In the Philippines, application of a 2:10 neem cake-urea mixture at 120 kg/ha reduced the incidence of ragged stunt, grassy stunt, and tungro viruses and significantly increased the rice yield more in both dry and wet seasons. Also, weekly ultra-low volume (ULV) spraying of 50% neem oil-custard apple oil mixture in 4:1 proportion (vol/vol) at 8 l/ha from seedling to the maximum tillering stage decreased the tungo incidence and increased the yield (Table 1) (Abdul-Kareem *et al*. 1987). The low input cost of the treatment contributed to a high net gain compared with the insecticide treatment. In India, neem treatments controlled populations of the green leafhopper, the yellow stem borer, the rice gall midge, and grasshoppers. Plots sprayed with 2% neem seed extract at 10 kg/ha yielded the highest grain yield.

Maize, sorghum, and millet. In trials conducted at the Mbita Point Field Station of International Centre of Insect Physiology and Ecology (ICIPE) and in farmers' fields in Kenya, foliar application of powdered neem seed at 3 g/plant or powdered neem cake at 1 g/plant once at 4 weeks after crop emergence (WE) or twice at 4- and 6 WE to maize, which had been infested with the spotted stem borer, significantly reduced the foliar damage, stem tunneling, tassel breakage, and populations of borer larvae. Grain yield in neem-treated maize plots was as high as that obtained with insecticides and significantly higher than that in untreated control plots (Table 2). Storage of neem cake up to 2 years in the dark did not reduce its pest effectiveness (Table 3). Similar reduction in pest damage, including their body size measured by the width of larval head capsules, and increase in yield were obtained when neem cake was applied to sorghum crop (Table 4). In trials conducted in Mali, the use

Table 2. Tassel breakage by *Chilo partellus* (Swinhoe) larvae and grain yield in plots planted to stemborer-susceptible 'Katumani' maize cultivar and applied with neem seed powder (NSP) or Furadan. ICIPE Field Station and farmer's field, Mbita, Kenya, short-rains cropping season 1992 (Saxena, unpubl.)[1]

Treatment	ICIPE Field Station Tassel breakage (%)	ICIPE Field Station Yield (kg/ha)	Farmer's Field Tassel breakage (%)	Farmer's Field Yield (kg/ha)
NSP basal	17.0b	4530b	12.0b	3570b
NSP (foliar)	2.0a	6430a	4.0a	5480a
NSP (basal + foliar)	2.0a	5870a	2.0a	5630a
Furadan 5G	0.3a	6400a	0.3a	6130a
Untreated (control)	21.0b	3370b	17.0c	3850b

[1] Within a column, means followed by a common letter are not significantly different at the 5% level by the LSD test; averages of 4 replications.

Table 3. Infestation and plant damage by *Chilo partellus* and *Eldana saccharina* (Walker) larvae and grain yield in plots planted to moderately resistant ICZ5 maize cultivar and applied with neem cake (NC) or an insecticide. ICIPE Field Station, Mbita, Kenya, long-rains cropping season 1994 (Saxena, 1998)[1]

Treatment	Damage[2] 9WE	Plant height (cm) 14WE	Tunnel length (cm) 7WE	Tunnel length (cm) 14WE	*Chilo* (no.)3	*Eldana* (no.)[4]	% tassel breakage[5]	Yield (kg/ha)
Fresh NC	2.4a	180ab	0.6a	15.6a	1.5a	7.8a	8.6a	7458a
1-yr-old NC	2.4a	186a	0.7a	13.0a	1.5a	6.5a	8.1a	7760a
2-yr-old NC	2.4a	185a	0.6a	18.5a	0.3a	9.4a	9.4a	7469a
Dipterex	2.1a	177ab	0.5a	20.3ab	1.5a	17.0a	17.0a	7271a
Untreated (control)	4.6b	167b	7.8b	31.6b	14.3b	25.5b	35.5b	5088b

[1] Within a column, means followed by a common letter are not significantly different at the 5% level by LSD test; averages of 4 replications.
[2] Foliar damage scored visually on 1-9 scale (1 = no damage, 9 = completely damaged). [3,4,5] *Chilo* larvae were recorded at 9 WE, *Eldana* larvae at 11 WE, and tassel breakage at 11 WE.

Table 4. Infestation and plant damage by *Chilo partellus* larvae and grain yield in plots planted to stemborer-susceptible 'Serena' sorghum cultivar and applied with neem cake (NC) once at 4 weeks after emergence (WE) or twice at 4- and 6 WE, or with Dipterex. Mbita, Kenya, short rains cropping season, 1994 (Saxena 1998)[1]

	Experiment Station						Farmer's Field					
	Foliar damage 9WE[2]	Plant height (cm) 9WE	Tunnel length (cm) 15WE	Larvae (no.) 9WE	Head width (cm)	Yield (kg/ha)	Foliar damage 9WE[2]	Plant height (cm) 9WE	Tunnel length (cm) 15WE	Larvae (no.)	Head width (cm)	Yield (kg/ha)
NC once	2.9ab	110a	27.5ab	7.4ab	0.66a	6182ab	2.9a	114a	25.4b	18.8b	0.64a	5242a
NC twice	2.9ab	106ab	21.3a	2.2a	0.67a	7312a	3.0a	112a	18.9a	16.8a	0.63a	5052a
Dipterex	2.3ab	117a	20.3a	7.0ab	0.79ab	6523ab	2.5a	111a	22.9ab	19.4ab	0.96c	5043a
Control (untreated)	3.5b	94b	30.3b	10.2b	0.84b	6056b	4.1b	99b	27.9b	25.8b	0.90b	3908b

[1] Within a column, means followed by the same letter are not significantly different at the 5% level by LSD test; averages of 4 replications.
[2] Foliar damage scored visually on 1-9 scale (1 = no damage, 9 = completely damaged).

Table 5. Effect of soil application of neem seed powder (NSP), neem cake (NC), neem kernel powder (NKP), or treatment with neem oil (NO) on population of banana nematodes at 2 and 8 months after treatment of pared or unpared banana suckers planted in drums. ICIPE, Mbita Point Field Station (Musabyimana and Saxena 1999a)[1]

Treatment	Nematode population at (no.)/100 g of roots ± SEM 2 months	8 months
Pared	1200 ± 489a	22200 ± 3747a
Unpared + NSP	200 ± 300a	3600 ± 490a
Pared + Furadan	0 ± 0a	16800 ± 2135a
Pared + NC	0 ± 0a	1200 ± 2135a
Pared + NSP	0 ± 0a	22500 ± 2265a
Pared + NKP	0 ± 0a	81600 ± 23510b
Unpared + NC	300 ± 300a	1200 ± 0a
Unpared + NO	0 ± 0a	5700 ± 1025a
Unpared + NKP	125 ± 125a	27600 ± 373a
Unpared (untreated)	25050 ± 4057b	114000 ± 4673b
CV%	95.7	50.4
Difference	**	**

[1] Means in columns followed by the same letter do not differ significantly ($P < 0.05$, Tukey's test); averages of 4 replications; ** = $P < 0.001$ (Tukey's test).

of local neem extract resulted in significant increase in yield of early and main season millet as a result of the control of millet head pests, blister beetle, and head miner.

Banana. The banana weevil, *Cosmopolites sordidus* (Germar), and parasitic nematodes are major pests of banana and plantain. They often occur together and may destroy the corm and the root system, resulting in loss of fruit yield. Most of the highland bananas in Eastern Africa are highly susceptible to the weevil and nematode infestations. Soil applications of neem seed powder or neem cake at 100 g/plant at planting and, subsequently, at 3-month interval, reduced the populations of the root-lesion nematode, *Pratylenchus goodeyi* and the root-knot nematodes, *Meladogyne* spp., on par with Furadan 5G applied at 40 g/plant at planting and then at 6-month-intervals to banana plants grown in 100 l containers with controlled levels of banana nematode infestations (Musabyimana and Saxena 1999a). Eight months after planting, banana plants treated with NC, NSP, kernel powder, or with oil had 7 to 95 times less parasitic nematodes than the untreated control. However, only NC or NSP applied to unpaired banana plants kept the nematode population below the economic threshold (Table 5). At 8 months after incorporation into the soil, NC or NSP application was still effective against banana nematodes, while the nematicidal activity of Furadan seemed to decline. Weevil larvae fed little or avoided altogether neem-treated corms, while extensive damage occurred on untreated corms. With neem treatment, fruit yield increased by 27-50% over the control in the first crop and by 30-60% over the control in the second crop, but yield with Furadan during the second crop was even less than that in the control (Musabyimana and Saxena 1999b). Neem application conferred a net economic gain, whereas Furadan application proved uneconomical (Musabyimana *et al.* 2000) (Table 5).

Grain legumes and vegetables. Because of high profitability of legumes and vegetables, farmers tend to overuse chemicals, which result in hazard to the environment and health of producer and consumer, as well as serious resistance problems. However, neem can provide satisfactory control of insect pests affecting grain legumes and vegetables. A wide range of pests attack cowpea, a major food crop in Africa. Sprays with neem seed extract were quite effective against lepidopterous pests, but weekly ULV spray applications of neem oil did not control the flower thrips, *Megalurothrips sjostedti* (Trybom) (Dreyer 1987). On the other hand, in trials conducted at ICIPE's Mbita Point Field Station and in a farmer's field in Kenya, applications of 2 or 3% neem seed extract at 200 L/ha at 38, 47, and 51 days after emergence (DE) of cow pea crop or ULV spray applications of 5, 10, or 20% NSE at 10 l/ha significantly reduced the number of thrips larvae in flowers recorded 2 days after each treatment (Saxena and Kidiavai 1997). Also fewer adults occurred in flowers at 51 DE in plots sprayed with 5%, 10% or 20% NSE. Grain yield was significantly higher in plots sprayed with 20% NSE than in control plots and was comparable to yield obtained in plots sprayed thrice with Cypermethrin (Table 7). Because of the

Table 6. Effects of neem seed powder (NSP), neem cake (NC), Furadan or a mixture of NC and Furadan applied at different rates to banana plants grown in a field with a moderate level of pest infestation and fertile soil on pest infestation, plant damage, fruit yield, and net gain during the 2nd crop cycle. Kabondo, Kenya, 1996 to 1999 (Musabyimana *et al.* 2001)

Treatment (g/mat)[1]	Necrosis index[2]	Nematodes (no./100g roots)	Weevils (no./plot)	PCI3 outer	Fruit yield (t/ha)	Yield value (US$/ha)[4]	Treatment (cost (US$/ha)[5]	Net gain (US$/ha)[6]
NSP 60	0.3ab	3533ab	3.0b	0.0a	19.9ab	1990	252	1738
NSP 80	0.0a	2667a	0.2a	0.7a	24.4a	2440	318	2122
NSP 100	0.0a	1800a	0.8ab	0.0a	19.9ab	1990	384	1606
NC 60	0.0a	2233a	1.8ab	0.2a	24.7a	2470	351	2119
NC 80	0.5ab	4733ab	2.1ab	0.0a	27.0a	2700	450	2250
NC 100	0.0ab	3530ab	1.0ab	2.3ab	18.7ab	1870	549	1321
Furadan 60	0.8ab	7273a	0.5a	3.0ab	15.1b	1510	801	709
Furadan 30 + NC 30	3.0ab	2800a	0.5a	1.2a	24.0a	2400	777	1623
Control (untreated)	1.3b	29533c	0.3a	5.6b	15.3b	1530	0	1530

[1] Within columns, means followed by a common letter do not differ significantly (P<0.05; Student-Neuman-Keuls test); averages of six replications.
[2] During the crop cycle, NSP, NC, or NC+Furadan was applied twice., [3] Percentage coefficient of infestation. [4] Price of banana fruit = US$0.1/kg (source: Market Information Branch., Ministry of Agriculture, Kenya., [5] Treatment cost: NSP = US$1/kg; NC = US$1.5/kg; Furadan = US$5.8/kg; labor = US$18/ha., [6] Net gain = yield value – treatment cost.

Table 7. Comparative yield and value of cowpea grain after deducting the cost of neem seed extract (NSE) or Cypermethrin applied thrice to cowpea crop. ICIPE Mbita Point Field Station. Long-rains cropping season; 1994 (Saxena and Kidiavai 1997)[1]

Treatment[2]	Grain yield (kg/ha)	Value of yield[3] (US$/ha)	Cost of treatment (US$/ha)	Value of yield - cost of treament[4]
		Field Station		
NSE 5%	1160ab	580	1.5	578.5
NSE 10%	1280ab	640	3.0	637.0
NSE 20%	1480a	740	6.0	734.0
Cypermethrin	1480a	740	108.0	632.0
Control (1% Teepol)	1050b	525	0.0	525.0
		Farmer's Field		
NSE 5%	1450d	725	1.5	723.5
NSE 10%	1630c	815	3.0	812.0
NSE 20%	1760b	880	6.0	874.0
Cypermethrin	2130a	1065	108.0	957.0
Control (1% Teepol)	1290e	645	0.0	645.0

[1] Means followed by a common letter do not differ significantly (P < 0.05; Ryan-Einot-Gabriel- Welsch Multiple Range Test).
[2] Using ultra-low volume applications, NSE or Cypermethrin was applied three times at 10 *l*/ha at 31, 39 and 49 days after crop emergence.
[3] 1US$ = KSh 54; cost of cowpea grain = 50/kg. [4] Treatment cost includes only cost of NSE or Cypermethrin; neem seed @ US$0.5/kg, Cypermethrin @ US$36/l.

low cost of NSE treatment, the net gain was often more when cowpea was sprayed with NSE than with the insecticide. Also, grain quality was superior in neem-treated plots than in control or Cypermethrin-treated plots.

In common beans, high volume spray applications of 2% neem kernel ectract at 11-day intervals effectively controlled the chrysomelid beetle, *Ootheca bennigsen* (Weise) (Karel 1989). Neem derivatives also proved effective against pod borers and bollworms on Bengal gram, against the leaf roller, and flea beetles on okra, and against pod borers and the pod fly on pigeon pea (Saxena 1989).

Kales, cabbages, and other crucifers are highly vulnerable to attack by the diamondback moth, *Plutella xylostella* L.. Synthetic insecticides do not provide long-term control as the pest is known to develop resistance rapidly (Talekar and Shelton 1993). In trials conducted in Togo, weekly high volume spray applications of 4% methanolic neem kernel extract (NKE) (Adhikary 1985) or even 2.25 to 5% aqueous NKE (Dreyer and Hellpap 1991) almost completely protected the cabbage crop against the pest. Similar results have been obtained in Asia. Other lepidopterous pests of cabbage and aphids are also controlled with neem. In repeated trials conducted at

Table 8. Comparative diamondback moth (DBM), *Plutella xylostella* L., infestation, spider population, and leaf yield in fields planted to a highly susceptible 'Southern Georgia' kale cultivar and sprayed with neem seed extract (NSE), azadirachtin-rich neem extractive (NE), or with Cypermethrin. ICIPE Field Station, Mbita, Kenya (Saxena, unpubl.)[1]

Treatment[2]	DBM (no.)/20 leaves	Spiders (no.)/20 leaves	Leaf yield (kg/ha)
		Short-rains Cropping Season 1997	
NSE 20%	41.8 ± 6.89a	_	14043 ± 1577a
NSE 20% + ajwan[3]	51.8 ± 9.98a	_	13737 ± 1497a
Cypermethrin	45.2 ± 7.21a	_	13972 ± 1931a
Untreated (control)	109.2 ± 14.86b	_	6630 ± 741b
		Site #1. Long-rains Cropping Season 1998	
NSE 20%	24.6 ± 3.82a	15.2 ± 3.79a	9841 ± 919.2a
NE 0.3%	51.6 ± 7.22b	16.0 ± 7.22a	6187 ± 482.1b
Cypermethrin	50.8 ± 6.04b	5.6 ± 1.21a	6131 ± 854.0b
Untreated (control)	85.8 ± 11.19c	17.6 ± 2.84a	5360 ± 947.4b
		Site #2. Long-rains Cropping Season 1998	
NSE 20%	10.2 ± 1.74a	18.0 ± 2.81a	20776 ± 1789a
NE 0.3%	14.6 ± 1.33a	21.6 ± 3.97a	12591 ± 1111b
Cypermethrin	16.2 ± 2.84a	8.6 ± 1.03a	14117 ± 1522b
Untreated (control)	35.6 ± 4.32b	20.2 ± 2.69a	13979 ± 1108b

[1] Means followed by a common letter do not differ significantly (P<0.001 for short-rains cropping season 1997 and for Site #1 long-rains cropping season 1998; P<0.002 for Site #2 long-rains cropping season 1998; Ryan-Einot-Gabriel-Welsch Multiple Range Test); avg. of 5 replications. [2] Using ULV applicator, NSE, NE or Cypermethrin Was applied to kale crop at 10-d intervals. [3] Ajwan is a natural antioxidant used as a spice in India.

ICIPE Field Station and in a farmer's field in western Kenya, ULV spray applications of 20% neem seed extract at 10-d intervals, significantly reduced the pest infestation and damage and increased the yield of marketable leaves of kale ('Sukuma-wiki' in Kiswahili language) (Table 8) (Saxena unpubl.). Spray applications of 0.3% neem extractive were not as good as neem seed extract treatment. The population of spiders, which are important predators of DBM larvae, was as high in neem-treated plots as in untreated control plots, while it was much lower in Cypermethrin-treated plots. During long rainy seasons, kale leaf yield was significantly higher with neem seed extract than with Cypermethrin. Economic returns with neem seed extract treatments were promising as the cost of neem seed is low.

In Africa, the root-knot nematodes, *Meloidogyne* spp., and the fruit borer, *Helicoverpa armigera* (Hübner) are the most damaging pests of tomato. As nematodes are "unseen enemies," their role in limiting tomato production in tropical regions is generally overlooked. Rössner and Zebitz (1987) and Parveen & Alam (1998) reported nematicidal effects of neem materials in tomato. In field trials conducted at ICIPE's Field Station at Mbita, Kenya in 1997-98, we found that, compared with untreated control, soil application of neem seed powder at 3 g/hill at planting significantly reduced the number of galls per plant on par with Furadan (Table 9). However, the nematicidal effects of neem seed powder treatment persisted much longer than that of Furadan. The fruit borer incidence was low, but as a precautionary measure against insect pest in general, neem seed extract, neem extractive, or Cypermethrin was sprayed with a ULV sprayer at 10 L/ha at 10-d intervals. Although fruit yield did not increase significantly with neem or pesticide treatment over the untreated control, the quality of fruits produced in neem-treated plots was distinctly superior. In Niger, weekly spray applications of 5% aqueous neem seed extract reduced the tomato fruit borer damage and increased the marketable fruit yield (Ostermann 1992).

Okra pests, such as the leaf-cutting caterpillar, *Sylepta derogata* Fabricious, was quite susceptible to spray applications of even at 0.25% aqueous neem kernel extract (Dreyer 1987) or 5, 10, or 20% aqueous neem seed extract (Cobbinah and Olei-Owusu 1988). Also, the cotton aphid, *Aphis gossypii,* was well controlled on okra by four weekly sprays of 0.5% aqueous neem seed extract or 2% neem oil; the effects being on par with Butocarboxim insecticide (Dreyer and Hellpap 1991).

In Niger, foliar applications of aqueous neem seed extract 0.25%, 0.5% or 1% to amaranth fields

Table 9. Comparison of root galls caused by root-knot nematodes in tomato plants treated with neem seed powder (NSP), neem seed extract (NSE), neem extractive (NE), or insecticide, and in untreated tomato plants. ICIPE Field Station, Mbita, Kenya (Saxena, unpubl.)[1]

Treatment[2]	Root gall score (0-10 scale) recorded at weeks after transplanting (WT)[3]		
	4 WT	6 WT	8 WT
	Short-rains Cropping Season 1997		
NSP (3g/plant), NSE 20%	2.1 ± 0.30a	1.4 ± 0.18a	-
NSP (3g/plant), NE 0.3%	1.6 ± 0.47a`	1.3 ± 0.26a	-
Furadan 5G (1g/plant), Cypermethrin	2.8 ± 0.33ab	2.4 ± 0.28a	-
Untreated (control)	3.9 ± 0.49b	2.2 ± 0.32a	-
	Short-rains Cropping Season 1998		
NSP (3g/plant), NSE 20%	1.8 ± 0.50a	0.9 ± 0.17a	-
NSP (3g/plant), NE 0.5%	2.1 ± 0.66a	2.2 ± 0.25b	-
NSP (3g/plant), NE 1.0%	2.0 ± 0.44a	1.1 ± 0.10a	-
Furadan 5G (1g/plant), Cypermethrin	2.2 ± 0.45a	0.9 ± 0.17a	-
Untreated (control)	4.4 ± 0.35b	4.7 ± 0.39c	-
	Short-rains Cropping Season 1999		
NSP (3g/plant), NSE 20%	1.6 ± 0.43a	1.4 ± 0.39a	0.8 ± 0.34a
NSP (3g/plant), NE 10%	1.9 ± 0.51a	1.7 ± 0.34a	1.5 ± 0.35ab
Furadan 5G (1g/plant), Cypermethrin	1.9 ± 0.28a	2.0 ± 0.23a	2.0 ± 0.36bc
Untreated (control)	3.1 ± 0.22b	3.5 ± 0.31b	2.8 ± 0.17c

[1] Means followed by a common letter do not differ significantly (P<0.001-0.05) for different cropping seasons; Ryan-Einot-Gabriel-Welsch (REGW) Multiple Range Test; average of 5 replications for 1997 and 1999; average of 4 replications for 1998. [2] Root gall score (on 0-10 scale); 0 = 0 galls per plant, 1 = 1-2, 2 = 3-5, 3 = 6-10, 4 = 11-15, 5 = 16-20, 7 = 31-40, 8 = 41-50, 9 = 51-60, 10 = 61 and above galls per plant. [3] Using ULV spray applicators, NSE, NE or Cypermethrin was applied to tomato crop at 10 *l*/ha at 10-d intervals.

strongly repelled *Spodoptera exigua* (Hübner) while a soil drench of 0.5% neem seed extract repelled *S. exigua*, while a soil drench of 0.5% neem seed extract repelled *Spodoptera littoralis* (Boisduval) (Ostermann 1992). Spray applications at 0.5% or 1% neem seed extract reduced the foliar damage by *S. exigua* significantly, while pre- and post-sowing soil drenches with 0.5% neem seed extract at 1000 l/ha stopped the immigration of *S. littoralis* larvae into treated fields and almost doubled the leaf yield over that of the untreated plots (Ostermann 1992).

In Sudan, remarkable results were obtained with neem products in the control of the sweet potato whitefly, *Bemisia tabaci* (Gennadius)and the leafhopper, *Jacobiasca lybica* (Bergenin &. Zanon) on potato (Siddig 1987, 1991). Two high volume applications of 2.5% aqueous neem kernel extract sprayed at fortnightly intervals significantly reduced the pest populations to >50% of the control and increased the yield. The potato tuber moth, *Phthorimaea operculella* (Zeller), was unaffected in the field but spray applications of 0.05% and 0.1% of neem oil strongly deterred oviposition and prevented damage in the stored potatoes (Siddig 1988).

Agroforestry and tobacco. Insects and nematodes also affect trees and crops in agroforestry. In collaborative trials conducted by International Centre for Research in Agroforestry (ICRAF) at Shinyanga in Tanzania in 1995-1996, application of powdered neem cake at 2g/plant to a hybrid maize, "Cargill," at 4 and 5 weeks after sowing, registered a 30% yield increase over the control (ICIPE 1998). Application of neem cake at 135 kg/ha also reduced the termite damage and significantly increased the grain yield of hybrid maize over the Furadan-treated or untreated crop. In a long-term trial conducted at ICRAF Field Station at Machakos, it was observed that when neem cake was applied at 15g/grevillea seedling, the tree mortality after 15 months was 60%, compared with 52% tree mortality in Furadan treatment, and 72% in untreated control.

In field trials conducted in Tabora, Tanzania, although application of neem seed powder or neem cake at 15 g/m^2 was not as effective as Ethylene dibromide at 62 ml/m^2 in reducing the root galling index in tobacco plants, the tobacco yield increased significantly with neem treatments (ICIPE 1998).

Table 10. *Tribolium castaneum* (*TC*), *Rhyzopertha dominica* (*RO*), *Sitophilus oryzae* (*SO*), *Oryzaephilus surinamensis* (*OS*), and *Corcyra cephalonica* (*CO*) adults and weevil attacked grains found in samples taken from rice treated prior to bagging and stored for 8 months in a warehouse in the Philippines. Pest infestation was low (0 – 0.7 adult/species/sample) and weevil attacked grains were few (0.2 – 0.4%) in rice grains sampled initially at one month after storage (Jilani and Saxena 1988).

Treatment	Conc.	Adult insects (no.) and weevil attacked grains in 250 g samples[1]					
		TC	RD	SO	OS	CC	Weevil attacked grains (%)
NO-treated bag	(1 mg/cm^2)	2.0a	5.0a	3.1a	2.4bc	2.7a	3.1a
NO-treated bag	(4 mg/cm^2)	3.0abc	5.0a	3.5ab	2.1abc	2.7a	3.3a
Fumigation+NO-treated bag	(1 mg/cm^2)	3.0abc	4.0a	3.1a	2.4bc	4.7abc	2.8a
Fumigation+NO-treated bag	(4 mg/cm^2)	2.7ab	4.0a	3.1a	2.4bc	4.0ab	3.2a
NO-treated rice	(0.05%)	2.3ab	5.3a	3.9ab	2.4bc	2.3a	2.8a
NO-treated rice	(0.1%)	1.7a	3.3a	3.5ab	2.4bc	2.7a	2.9a
Fumigation+NO-treated rice	(0.05%)	2.3ab	3.7a	3.5ab	1.2a	3.0a	3.1a
Fumigation+NO-treated rice	(0.1%)	1.7a	4.3a	3.1a	1.8ab	2.7a	2.8a
Actellic-treated bag	(25 μg/cm^2)	1.7a	3.7a	3.1a	2.1abc	2.3a	2.8a
Actellic-treated rice	(0.0005%)	3.0abc	3.0a	2.4a	1.2a	3.0a	3.3a
Phosphine fumigation	(1 g/m^3)	4.0bc	9.7b	5.3b	2.7bc	6.3bc	5.9b
Control	(untreated)	5.0c	10.0b	5.7b	3.5c	8.3c	10.6c

[1] In a column, means followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test (DMRT); averages of 3 replications per treatment.

Table 11. *T. castaneum* (*TC*), *R. dominica* (*RD*), *S. oryzae* (*SO*), *O. surinamensis* (*OS*), and *C. cephalonica* (*CC*) adults and weevil attacked grains found in samples taken from paddy treated prior to bagging and stored for 8 months in a warehouse in the Philippines. Pest infestation was low (0 – 0.7 adults/species/ sample) and weevil attacked grains were few (0.2 – 0.6%) in paddy grains sampled usually at one month after storage (Jilani and Saxena 1988).

Treatment	Conc.	Adult insects and weevil attacked grains in 250g samples[1]					
		TC (No.)	*RD* (No.)	*SO* (No.)	*OS* (No.)	*CC* (No.)	Weevil attacked grains (%)
NO-treated bag	(1 mg/cm^2)	1.3a	6.7bcd	4.3abc	2.1abc	0.7a	4.3ab
NO-treated bag	(4 mg/cm^2)	1.7ab	5.0abc	3.1a	1.2a	1.0a	3.3a
Fumigation+NO-treated bag	(1 mg/cm^2)	3.0b	3.3ab	3.5ab	2.4bc	1.0a	3.6ab
Fumigation+NO-treated bag	(4 mg/cm^2)	1.7ab	3.7ab	3.1a	1.8ab	1.0a	3.1a
NO-treated paddy	(0.05%)	2.3b	4.7abc	4.3abc	2.1abc	0.7a	3.3a
NO-treated paddy	(0.1%)	2.3b	6.0a-d	3.5ab	1.0a	1.0a	3.3a
Fumigation+NO-treated paddy	(0.05%)	1.0a	3.3ab	3.1a	3.1bc	0.7a	3.4a
Fumigation+NO-treated paddy	(0.1%)	1.3a	3.7ab	3.1a	2.4bc	1.0a	3.3a
Actellic-treated bag	(25 μg/cm^2)	1.0a	3.7ab	3.9ab	2.1abc	0.7a	3.1a
Actellic-treated paddy	(0.0005%)	2.7b	3.3ab	6.8cd	1.8ab	0.7a	3.7ab
Phosphine fumigation	(1 g/m^3)	3.3b	7.0cd	9.1d	2.7bc	1.3a	5.9b
Control	(untreated)	1.9ab	9.3d	5.7bc	3.5c	1.3a	13.3c

[1] In a column, means followed by the same letter are not significantly different at the 5% level by DMRT; averages of 3 replications per treatment.

3.0 PESTS OF STORED PRODUCTS

Post-harvest losses are notoriously high in developing countries. Worldwide losses in store reach up to 10 % of all stored grain, i.e. 13 million tons of grain lost due to insects or 100 million tons to failure to store properly. Saxena (2002) has reviewed the potential of neem against stored products: grain legumes, maize, sorghum, wheat, rice, and paddy, and potato tubers. At farm level storage and warehouses, the application of neem derivatives to bags and stored grains has provided protection against insect pests. Powdered neem seed kernel mixed with paddy (1 to 2 %) significantly reduced infestation in warehouses. Neem leaves mixed with paddy (2 %), bags treated with 2% neem seed extract, or 20 - 30cm dried neem leaf barrier between the bags and storage floor significantly reduced insect infestation and damage to grain during a 3-month storage period; the effectiveness being comparable to Methacrifos dust. Likewise, neem seed extract at 7.2 g/90 kg capacity

Table 12. Growth, development, and fecundity of *A. variegatum, R. appendiculatus,* and *B. decoloratus* ticks on rabbit hosts treated with neem oil (Kaaya *et al*. 2007)[1].

Treatment	Engorgement duration (d) Larva	Engorgement duration (d) Nymph	Engorgement weight (mg) Larva	Engorgement weight (mg) Nymph	Engorgement weight (mg) Adult	Molting (%) Larva	Molting (%) Nymph	Weight (mg) per egg mass	Hatchability (%)
				A. variegatum					
Neem oil	10a	16a	43±19a	44±1b	211±8a	66±1.3a	94±3.3a	940± 1a	31±2.0a
Peanut oil (control)	6b	9b	43± 4a	35±1a	306±6b	85±0.7b	94±3.3a	1320±20b	68±1.8b
				R. appendiculatus					
Neem oil	5a	5a	8±0.6a	9±0.1a	295±10a	50±0.8a	94±0.9a	100±10a	52±5.8a
Peanut oil (control)	5a	5a	8±0.1a	9±0.3a	388±10b	87±1.2b	94±0.9a	182±10b	100±2.3b
				B. decoloratus					
Neem oil	--2	--2	--2	--2	--2	2±0.1a	--2	39±0.2a	43±0.6a
Peanut oil (control)	--2	--2	--2	--2	--2	86±0.6b	--2	57±0.1b	88±1.2b

[1] For a particular species, within a column, means followed by the same letter are not significantly different ($P<0.05$; REGW Multiple Range Test). [2] Not tested.

jute bag (100 x 60 cm) controlled 80 % population of major insects and checked the damage to wheat up to 6 months. The treatment was effective up to 13 months and provided more than 70% protection as compared with untreated control. The neem seed extract treatment was as effective as that of 0.0005 % Primiphos methyl mixed with the grain. Using the technology in Sind, Pakistan, high benefit-cost ratios were obtained by small-, medium-, and large-scale farmers (Jilani and Amir 1987).

The effectiveness of neem oil alone or in combination with fumigants was evaluated against five major species of stored grain pests infesting rice and paddy grains in a warehouse trial conducted in the Philippines (Jilani and Saxena 1988). Rice grain treated with 0.05 – 0.1 % neem oil or treated with neem oil after fumigation with Phostoxin, and stored for 8 months had significantly less *Tribolium castaneum* adults than in untreated control (Table 10). Both kinds of treatments were as effective as the bag treatment with Actellic at 25 µg/cm^2 or grain treatment with Actellic at 0.0005%, and suppressed the pest population by 60 %. The population build-up was also reduced when fumigated or non-fumigated rice was stored in bags treated with neem oil at >1 mg/cm^2. *Rhyzopertha dominica* Fabricius, *Sitophilus oryzae* (L.), *Oryzaephilus surinamensis* (L.) and *Corcyra cephalonica* Stainton were similarly reduced by neem treatments alone or in combination with prior grain fumigation (Table 10). Fumigation and Phostoxin were effective only for about 2 months against *R. dominica,* and for up to 6 months against other pest species. In contrast, neem oil treatments were effective up to 8 months. Compared with the pest damage to untreated or fumigated rice, neem oil treatments significantly reduced the damage to rice grain. At 8 months after storage, weevil attacked grains in neem treatments were 50% of those in the fumigated rice and 25% of those in untreated rice.

Paddy grain that had been fumigated and then treated with neem oil or, after fumigation, stored in neem oil-treated bags, also had fewer adults of *T. castaneum, R. dominica, S. oryzae,* and *O. surinamensis,* as compared with the fumigated or the untreated paddy grain (Table 11).

C. cephalonica infestation was found in the stored paddy only after 4 months and remained low throughout the trial in treated as well as untreated paddy. Neem treatments also decreased the per cent weevil attacked grains by about 70% or more. Compared with fumigation, which was effective for only 2 months, neem treatments conferred protection against the stored grain pests for up to 8 months, after which the trial was terminated.

The efficacy of neem oil against some species of stored grain pests was confirmed in laboratory bioassays. In a choice test, filter paper strips treated with >200 µg/

cm^2 of neem oil repelled *T. castaneum* adults and in a food preference chamber fewer adults settled in grain treated with >100 ppm of neem oil (Jilani *et al*. 1988). *Tribolium castaneum* adults fed wheat flour, which had been treated with 200 ppm of neem oil, produced fewer and underweight larvae, pupae, and adults, compared with the control. Likewise, in choice tests, *R. dominica* adults were strongly repelled by filter paper strips treated with neem oil or Margosan-O, a neem-based commercial insecticide at >200 µg/cm^2 (Jilani and Saxena 1990). The borer made significantly smaller feeding punctures in filter paper disks treated with neem oil or Margosan-O at >100 µg/cm^2 than in untreated control disks. The effects of neem oil and Margosan-O persisted long enough to give a satisfactory result, as generally seen in field trials.

In studies conducted in Kenya, the growth and development of 1st-instars of the maize weevil, *Sitophilus zeamais*, was completely arrested in maize grain treated with neem oil at 0.02%, while the weight loss of treated cobs was less than 1% as compared with 50 % reduction in weight of untreated cobs stored for 6 months (Kega and Saxena 1996).

While neem cannot completely replace chemical pesticides used in stored products preservation, the amounts of pesticide needed could be reduced, particularly in developing countries, thereby decreasing the pesticide load in food grains. With proper timing and innovative methods of application, their use could be well integrated in stored products pest management.

4.0 BLOOD-SUCKING PESTS

The effects of neem on hematophagous insects affecting humans and livestock have been reviewed (Ascher and Meisner 1989). Application of paste made from neem leaves and turmeric in 4:1 proportion to the skin cured 87 % of the patients suffering from scabies caused by itch mite in 3-15 days. Monthly spray applications of ethanolic extracts of neem or weekly bathing in azadirachtin-rich aqueous 1:20 'Green Gold' controlled the bush tick in Australia, but were less effective against the brown dog tick (Rice 1993). In Jamaica, neem kernel extract controlled ticks on cattle and dogs. In Kenya, engorgement duration of larvae and nymphs of *Amblyomma variegatum* and larvae of *Rhipicephalus appendiculatus* were significantly prolonged due to slowed feeding on rabbit host sprayed with neem oil (Table 12) (Kaaya *et al*. 2007). Neem treatment also led to a reduction in engorgement weight of larvae, nymphs, and adults of *A. variegatum, R. appendiculatus,* and *Boophilus decoloratus* feeding on neem-treated rabbits and fewer larvae and nymphs molted to the next developmental stage. Egg masses produced by neem-treated ticks weighed significantly less while hatchability of their eggs was adversely affected. Regardless of tick species, attachment by larvae also was significantly reduced on neem oil-treated rabbits. In trials conducted in pastures in Kenya, application of neem oil on cattle repelled all stages of *R. appendiculatus, B. decoloratus,* and *A. variegatum* (Kaaya *et al*. 2007).

Neem products also repel and affect the development of mosquitoes. Two percent neem oil mixed in coconut oil, when applied to exposed body parts of human volunteers, provided complete protection for 12 h from bites of all anophilines (Sharma *et al*. 1993). Kerosene lamps containing 0.01-1% neem oil, lighted in rooms containing human volunteers, reduced mosquito biting activity as well as catches of mosquitoes resting on walls in the rooms; protection was greater against *Anopheles* than against *Culex*. Effectiveness of mats with neem oil against mosquitoes has also been demonstrated; the vaporizing oil repelled mosquitoes for 5-7 h at almost negligible cost. The sandfly also was totally repelled by neem oil, mixed with coconut oil or mustard oil, throughout the night under field conditions. Application of neem cake at 500 kg/ha, either alone or mixed with urea, in paddy fields was very effective and reduced the number of pupae of *Culex tritaeniorhynchus*, the vector of Japanese encephalitis, and also resulted in higher grain yield (ref).

5.0 PEST RESISTANCE TO NEEM MATERIALS

A few herbivorous insects, including some sucking insects, some beetles, and some moths do survive on neem but, largely, the tree is free from serious pest problems. Some insects can adapt to limonoids, but in laboratory tests two genetically different strains of the diamondback moth treated with a neem seed extract showed no sign of resistance in feeding and fecundity tests up to 35 generations (Völlinger 1987; Völlinger and Schmutterer 2002). In contrast, deltamethrin-treated lines developed resistance factor of 20 in one line and 35 in the other. There was no cross resistance between Deltamethrin and neem seed extract in the

Deltamethrin-resistant lines. The diversity of neem compounds and their combined effects on insect pests seem to confer a built-in resistance prevention mechanism in neem. However, wisdom demands that users should refrain from exclusive and extended application of single bio-active materials, such as azadirachtin.

6.0 ENVIRONMENTAL SERVICE AND OTHER BENEFITS

6.1 *Environmental Service*

Neem in India has been ranked higher than the *'Kalpavriksha'*, the mythological wish-fulfilling tree. Although scientific studies are wanting, neem is reputed to purify air and the environment of noxious elements. Its shade not only cools but also prevents the occurrence of many diseases. During hot summer months in northern parts of the Indian sub-continent, the temperature under the neem tree is -10°C less than the surrounding temperature. Restoration of the health of degraded soils and the ultimate use of such reclaimed wastelands through neem is another example of its value to humans. About 25 years ago, some 50,000 neem trees were planted over 10 km^2 on the plains of Arafat to provide shade for Muslim pilgrims during hajj (Ahmed *et al*. 1989). The neem plantation has had a marked impact on the area's microclimate, microflora, microfauna, and soil properties, and the full-grown trees provide shade to about 2 million pilgrims. In the last decade, about 25 million neem trees have been grown in southern China, especially in Yunnan province.

The tree is not only beautiful to look at, providing grandeur and serenity, but also serves as a refugia to many beneficial organisms, bats, birds, honey bees, spiders, etc. Honeycombs established on the neem tree are free from galleria wax moth infestation. Many species of birds and fruit-eating bats subsist on the sweet flesh of ripe fruits, while certain rodents selectively feed on the kernel, confirming neem's safety to warm-blooded animals. The litter of falling leaves improves soil fertility and the organic content. Recently, mycorrhizal associations between neem and bacterial and fungal endophytes have been identified. Indeed, the neem tree is a living microcosm.

The evergreen, perennial tree can survive 250 to 300 years. Even a highly conservative estimate of the intangible 'environmental service' rendered by the tree at US$ 10 per month over its lifetime would give an astonishing value of US$ 30,000 to 36,000. Other tangible economic uses of neem and the benefits derived, such as biomass production, timber, seed, and honey are quantifiable.

6.2 *Reforestation and Agroforestry*

Neem is a very valuable forestry species in Asia and Africa and also becoming popular in Tropical America, the Middle East countries, and in Australia. Nineteenth century immigrants carried the tree from India to Fiji, and it has since then spread to other islands in the South Pacific, even to Easter Island, which is hardly known as a place for trees (ref). Being a hard, multipurpose tree, it is ideal for reforestation programs and for rehabilitating degraded, semiarid, and arid lands, and coastal areas. During a severe drought in Tamil Nadu, India in June-July 1987, it was witnessed that neem grew luxuriantly, while other vegetation dried up.

Neem is useful as windbreaks. In areas of low rainfall and high wind speed, the neem tree can protect crops from desiccation. In the Majjia valley in Niger, over 500 km of windbreaks comprised of double rows of neem trees have been planted to protect millet crops, which reportedly resulted in a 20% increase in grain yield. Neem windbreaks on a smaller scale have also been grown along sisal plantations in coastal Kenya. Large-scale planting of neem has been initiated in Kwimba Afforestation Scheme in Tanzania and at Adjumani in northern Uganda.

In countries from Somalia to Mauritania, neem has been used for halting the spread of the Sahara desert. Also, neem is a preferred tree along avenues, in markets, and near homesteads because of the shade it provides. However, neem is best planted in mixed stands. It was probably no coincidence that Emperor Ashoka, the great ruler of ancient India, in the 3rd century BC, commanded that neem be planted along the royal highway and roads along with other perennials – tamarind and 'mahua'. Neem has all the good characters for various social forestry programs.

Neem is an excellent tree for silvipastoral system involving production of forage grasses and legumes. But according to some reports neem cannot be grown among agricultural crops due to it aggressive habit. Others say that neem can be planted in combination with fruit cultures and crops such as sesame, cotton, hemp, peanuts, beans, sorghum, cassava, etc., particularly when neem trees are still young. The neem tree can be lopped to reduce shading and to provide fodder and mulch. Recent advances in tissue culture and biotechnology should make it possible to select neem phenotypes with desirable height and stature for use in intercropping and various agroforestry systems. The allelopathic effects of neem on crops, if any, need to be investigated.

6.3 *Biomass Production and Utilization*

Full-grown neem trees yield between 10 to 100 tons of dried biomass/ha, depending on rainfall, site characteristics, spacing, ecotype or genotype. Leaves comprise about 50 % of the biomass, fruits, and wood constitute one-quarter each. Improved management of neem stands can yield harvests of about 12.5 cubic meter (40 tons) of high quality wood/ha.

Neem wood is hard and relatively heavy and is generally used for making carts, tool handles, farm implements, and even toys, and religious icons in some parts of India. The wood seasons well, except for end splitting. Being durable and termite resistant, neem wood is used in making fence posts, poles for house construction, furniture, etc. There is a growing market in some European countries for light-colored neem wood for making household furniture. Pole wood is especially important in developing countries; the tree's ability to re-sprout after cutting and to re-grow its canopy after pollarding makes it highly to pole production. Neem grows fast and is a good source of firewood and fuels; the charcoal has high calorific value.

7.0 NEEM FOR MITIGATING RURAL POVERTY

Poverty is not necessarily the want of money or cash in hand. In a wider sense, it is the lack of options, whether it is the non-availability of fertilizer for crop cultivation or pesticides for crop protection, medical remedies for family welfare, fuel or firewood for cooking, timber for furniture or dwelling, or the availability of appropriate technology for restoring wastelands, or absence of income generation and employment opportunities. In all these respects, neem could be a 'panacea,' particularly in rural areas. In India, during the neem fruiting season in June-July, seed collection provides employment and income to unemployed women, children, and infirm people. With growing demand worldwide for neem seed, neem honey, and other neem products, there is substantial scope for establishing cottage industries, and other small-scale enterprises in rural areas of Asia and Africa where neem is widespread. Since agriculture is the staff of life in rural areas, enhanced agricultural productivity through the use of neem products in pest management could significantly contribute to alleviation of poverty in rural areas.

8.0 RECENT DEVELOPMENTS ON NEEM IN THE DEVELOPED WORLD

For nearly the past three decades, neem has come under close scientific scrutiny as a source of natural insect control material in numerous international conferences, mostly held in developed countries such as Germany, Canada, Australia, USA, etc. Nearly 3,000 scientific papers have been published to date on neem. Australia with its large tracts of unused arid and semi-arid lands may become a major grower of neem in the next couple of decades.

The interest in neem in the developed world is attributable to the fact that neem-based pest control products with diverse modes of action are not only effective against pests, but also inherently safer, less persistent in the environment, and less prone to the problem of pest resistance than the synthetic pesticides. Technical grade neem active ingredients, principally azadirachtins, fetch the highest price, about US$ 375/kg as compared with US$ 75/kg for pyrethrum (Isman 1995). In 1989, the use of 'Margosan', containing 0.3% azadirachtin, was granted approval from the US Environmental Agency for non-food uses on ornamentals and landscape plants; in 1993 EPA approved the use of neem products, such as 'Neemix' on food crops. The U.S. based W.R. Grace Co., which holds patents from the U.S. Patent and Trademarks Office on the method of extracting the insecticide from neem, is advertising 'Neemix' as a "modern technology from ancient trees". Agridyne, another U.S. based company is marketing 'Align' (with 3% azadirachtin and 97% inert ingredients, mainly other neem limonoids) for control of insect pests in vegetable, fruit, nut, and agronomic crops. Both products are now being used for commercial-scale crop protection in the USA. Neem seed extracts are being used for forest insect pest management in Canada. Neem-based pesticides are expected to capture 10% of the global pesticide market in the next decade.A technique using a neem extract as a fungicide has also been patented in the USA. Worldwide, nearly 50 patents have been granted on neem so far. The use of additives, adjuvants, activators, and even Bt are being examined for potentiating the activity of azadirachtins against insect pests.

The patenting of neem pesticides and their formulations has evoked serious criticism and challenge in the developing world, particularly in India, as an example of 'folk wisdom piracy'. Efforts were made in some European countries to extract azadirachtin on a commercial scale from neem calli. But such ventures remained nonviable and economically unjustifiable. Quality neem seed with high azadirachtin content would remain the basic raw material for production of neem-based insecticides of the future. In that context, tropical countries of Asia and Africa could become major exporters of the raw material or even value-added finished products.

9.0 CONCLUSION

In the coming decades, the developing world would be facing four distressing crises, all counter-productive impacts of increased human activity and failure to use natural resources in a sustainable manner: ***1. Threat to food security*** due to population pressure, ***2. Rural and urban poverty*** and joblessness, ***3. Pollution*** and degradation of arable land and water bodies, and ***4. Loss of biodiversity.*** Neem has much to offer in solving global agricultural, public health, population, and environmental pollution problems. Certainly, it cannot be achieved without ***building awareness*** of its potential and ***dissemination of neem-based technology*** whether for pest management, public health, reforestation, or production and commercialization of various neem products for domestic use or exports. ***More neem trees of superior ecotypes or genotypes will have to be grown,*** particularly as a strategy for restoring marginal lands and making them productive and remunerative. Certainly, this would not happen overnight. If we are planning for long-term sustainability, then an investment in a time frame of five to 10 years is insignificant. Also, financial support, backed by favorable policies for neem promotion, production, and commercialization will be necessary.

As pointed out above, the demand for neem products, especially the seed as the basic raw material, is going to increase by leaps and bounds. Here in also lies a solution for creating income generation and job opportunities in rural and tribal areas. Neem-based industries in urban and industrialized regions would also create job slots for producing value-added products for domestic consumption and exports. Neem should also play a significant role in enriching the floral and faunal biodiversity as a huge variety of organisms, from insects to birds and mammals subsist on neem. Increased planting of neem along roadsides and avenues should make the cities more liveable and make rural areas more attractive than now. Use of neem-based pest control agents and fertilizers should reduce pesticide-related hazards and pollution on land and in water bodies. In fact, the neem story is just unfolding. Tropical countries where neem can thrive have much to gain from increased awareness of neem's hidden 'treasures'.

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RESEARCH PAPER

Brown spot rot, a new disease of aloe caused by *Fusarium thapsinum* Klittich, Leslie, Nelson & Marasas (telemorph: *Gibberella thapsina*)

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ABSTRACT

In January 2009 samples of natural infected *Aloe arborescens* were collected from Parks around Atsugi and nearby vicinities around the Hon-Atsugi Campus. The pathogenic fungus was isolated, and identified as a *Fusarium sp.* Koch's Postulates was carried out on Aloe arborescens which was very pathogenic and the same pathogen was isolated from infected *Aloe arborescens* tissues. Six other Aloe species also showed necrotic lesions when post inoculated with the *Fusarium* sp. Morphology and Phylogenetic analysis indicate *Fusarium thapsinum* Klittich, Leslie, Nelson & Marasas to be the causal pathogen. This is a new disease on *Aloe arborescens* caused by *F. thapsinum* and the name Brown spot rot of aloe is proposed.

Key words: *Fusarium thapsinum,* Koch's postulates, *Aloe arborescens.*

1.0 INTRODUCTION

Aloe, also written Aloë, is a genus containing about four hundred species of flowering succulent plants. The genus *Aloe* in the family Liliaceae is a group of plants including *Aloe vera* (*Aloe barbadensis* Miller) and *Aloe arborescens* (*Aloe arborescens* Miller var. natalensis Berger) that are empirically known to have various medical efficacies. *Aloe aborescens,* a member of the lily family, is a spiky, succulent, perennial plant. It is indigenous to eastern and southern Africa, but has been spread throughout many of the warmer regions of the world, and is also popularly grown indoors. *Fusarium thapsinum,* with its telemorph *Gibberella thapsina* was first described by Klittich *et al.* 1997. It causes stalk rot and grain mould of sorghum (Reed *et al.* 1983; Prom *et al.* 2004) and very pathogenic to sorghum seedlings invitro (Lesile *et al.* 2005) and can also reduce germination. It can also cause stalk rot of maize under green house conditions (Jardine *et al.* 1999) but not commonly isolated from maize under field conditions. *Fusarium thapsinum* is also recovered from maize, bananas, peanut, and sorghum in Egypt, South Africa, the Philippines, Thailand and nine states in the United States (Klittich *et al.* 1997). *F. thapsinum* is toxic to ducklings and can produce high levels of moniliformin, and no traces of fumonisins (Klittich *et al.* 1997; Nyvall. 1999).

Natural diseased *Aloe arborescens* plants collected around Atsugi, Kanagawa had soft necrotic tissues, brown, orange to yellow in color around the infected region of young leaves. Older leaves were black, brittle, and had shrunken lesions that cracked and developed holes on the petioles of the *A. aborescens* plants. This study sought to determine the causal agent of this newly occurring disease by its morphology, cultural properties, pathogenicity and phylogenetic features.

2.0 MATERIALS AND METHODS

2.1 *Fungal isolation*

Fungal isolation was done on potato-dextrose agar (PDA, Difco) and 2% water agar (WA). Shrunken and rotting leaf tissues of *Aloe arborescens* were incised and placed in 70% alcohol for 2 mins and 2% sodium hypochlorite solution for 3 mins. These materials were then rinsed in sterilized distilled water for 10 mins, then placed on PDA medium and incubated at room temperature. Single conidia isolation was done on Water agar (WA) to obtain pure isolate of the pathogenic fungus.

2.2 *Pathogenicity test*

In the first series leaves of *Aloe arborescens,* and *A. vera* were washed under running water for 1hr to eliminate contaminates. These leaves were then placed on wet tissue in plastic containers. Using cork borer mycelial disks (8 mm diam.) were taken from the edges of the 8-10 days old fungal colony were used as inocula. Sterile needles were used to injure the leaf mid ribs of the two aloe sp. and these inocula were then placed upside-down onto the wounded areas using a sterile scalpel. Inocula were also placed on non-wounded mid rips of *A. arborescens* and *A. vera,* to check for natural infection. Injured and non injured aloe leaves without inocula were used as control and all containers were kept in room temperature (25°C) and results obtained after seven days.

The second series of tests compared the pathogenicity of the representative isolate inoculated on seven Aloe species, *A. arborescens, A. vera, A. compacta, A. ibitensia, A. capittata, A. nobilis* and *A. congorens.* These Aloe species were purchased from a nearby hardware store. Leaves were injured using sterile needles and inoculum was placed upside-down onto the wounded areas. Injured leaves without inocula were used as control. To enhance disease development, treated and control plants were misted once a day (every morning) for seven consecutive days. PDA disks (8mm) without inocula was placed on injured aloe leaves as control.

In the third series of tests pathogenicity of the representative isolate was inoculated on wounded *A. arborescens* and *A. vera* plants. 1) Ten milliliters of AoEFg 01 spore suspension (1 x 106 conidia/ml) was sprayed onto the aloe plants. 2) Inocula (8mm diam.) of AoEFg 01 was placed upside-down on wounded aloe leaves. 3) Ten milliliters of AoEFg 01 spore suspension (1 x 106 conidia/ml) was poured into pots after aloe roots were wounded using sterile sharp object. Two plants were inoculated per plant species with 1 plant used as control. All plants were covered with plastic bags after inoculation and the bags were removed after 24 hours and aloe plants kept in the green house for the duration of the experiment. Sterilized water and non inocula was used as a control.

Observation of the severity of the symptom was done three days and seven days after inoculation. The severity of the symptom was determined as follows:- (no symptom: healthy plant), + (mild symptom: plant showing slight yellowing), ++ (moderate symptom: plant showing definite yellowing and some loss of turgour), +++ (severe symptom: enlarged lesions) (Table 2). Two experiments were conducted in September and October 2009, respectively.

2.3 *Optimum growth temperature*
Isolate AoEFg the representative strain of the pathogen fungus was cultured onto PDA plates and kept at 25°C for 6-7 days. Fungal disks 8mm in diameter were obtained by cork borer from the newly growing marginal area of AoEFg 01. Mycelium disks were placed upside-down on the center of PDA plate, using a sterile scalpel. Then each plate was sealed with parafilm and incubated in the temperature gradient chamber TG/100-ADGT that had temperatures adjusted at 5, 10, 15, 20, 25, 28, 30, 35 and 40°C. Five Petri dishes were placed in each chamber and the experiment was replicated twice.

The diameter of AoEFg 01 fungal strain was measured diagonally and horizontally using a Mitutoyo calibrating ruler and averages were calculated daily to determine colony growth daily at various temperatures. The combined averages of the two replications were then calculated and plotted.

2.4 *Morphological characterization*
As for macroscopic characteristics, AoEFg 01 isolate was grown on oatmeal agar and/or potato-dextrose agar for 8-10 days and aerial mycelium, vegetation mycelium, colony color and odor were then examined. AoEFg 01 was also grown on minimal media (Correll *et al*. 1987) to observe pigmentation and on Soil Agar (SA) to observe Chlamydospore formation (Klotz *et al*., 1988).

To determine microscopic characteristics AoEFg 01 fungal isolate was inoculated and grown on Spezieller Nahrstoffarmer Agar (Nirenberg., 1976) and Carnation Leaf Agar (CLA; Fisher *et al*. 1982) and kept in a 25 degrees chamber in the dark and under continuous BLB for 14 days and observed under light microscope.

2.5 *Phylogenetic analysis*
Extraction of DNA for Phylogenetic analysis was done using the mini preparation method described by Saitoh *et al*., 2006. PCR was done on prepared DNA to amplify the internal transcribed spacer (ITS) region. The primer pairs used were ITS1 (5`-TCCGTAGGTGAACCTGCG-3`) and ITS4 (5`-TCCTCCGCTTATTGATAT-3`) (White *et al*., 1990).

Polymerase chain reaction amplification of ITS genes was performed with the Takara ExTaq system (Takara Bio. Otsu Japan), with a first denaturation for 2 min at 94°C followed by 30 cycles of incubation for 30s at 94°C, 30 s at 57°C, 1 min at 72°C and a final extension of 7 min at 72°C. Sequencing was conducted with the ABI-PRISM 377 DNA sequencing system (Applied Biosystems, Foster City, USA) and DNA sequencing kit (Perkin-Elmer, Foster City, USA) following the ABI protocol, by using the same primer pairs as described above. Phylogenetic analysis used segment of ca 700 nucleotides including four introns and exons in ITS genes.

The length differences were compensated in the alignments by gaps. The sequence alignment and homology analysis were carried out using Assembly LIGNTM 1.0.9c (Accelrys, San Diego, USA) and the CLUSTAL W package with Mac Vector 6.5.3 (Accelrys) (Thompson *et al*. 1994). The aligned sequences were analyzed by the neighbor-joining method (Saitou and Nei 1987). Using PAUP 4.0b (Swofford 1998). The distance matrix was calculated using DNADIST with the Kimura's two-parameter method (Kimura 1980), and the topology was tested with 1,000 bootstrap trials.

3.0 RESULTS

3.1 *Fungal Isolated*
The fungal isolate was obtained and named AoEFg 01. Single spore isolation was carried out on water agar and Koch's postulates confirmed AoEFg 01 isolate to be pathogenic to *Aloe arborescens.* AoEFg 01 isolate was used in this study. AoEFg 01 was streaked into PDA slants and kept at 25 degrees room temperature for future use.

3.2 *Pathogenicity of Fungal Isolates*
Fungal isolate AoEFg 01 was very pathogenic only to wound inoculated *A. aborescens* and *A. vera.* Non-wounded aloe showed no signs of infection when inoculated with AoEfg 01 (Table 1).

Six out of seven of the Aloe species tested were very pathogenic to the representative isolate. *A. arborescens, A. vera, A. compacta, A. ibitensia, A. capittata,* and *A. nobilis* showed severe symptoms of wet, rotting and shrunken lesions on infected leaves (Table 2). *Aloe congorens* showed moderate symptoms in that only the injured inoculated leaves were infected. Infected leaves turned blackish, brownish and yellowish in color and

Table 1. AoEFg 01 inocula on wounded and non wounded *A. arborescens* and *A. vera* after 7 days.

Treatment	*A. arborescens*		*A. vera*	
	Inoculated[a]	Diseased	Inoculated[a]	Diseased
Wound inoculation	2	2	2	2
Non-wound inoculation	2	0	2	0
Control	2	0	2	0

a) AoEF 01 mycelium disks (8mm)

Table 2. Pathogenicity of AoEFg 01 fungal isolate tested on seven species of Aloe plants at 7 and 14 days.

Strain *Aloe sp*. inoculated		Control[c] AoEFg 01(8mm) mycelia disks	
	Injured[a]	Non-injured [b]	Injured[a,b]
Aloe arborescens	+++	+++	-
A. vera	+++	+++	-
A. capittata	+++	+++	-
A. compacta	+++	+++	-
A. congorens	++	-	-
A. ibitensia	+++	+++	-
A. nobilis	+++	+++	-

- (No symptom), + (mild symptom), ++ (moderate symptom), and +++ (severe symptom).
a) Injured leaves of aloe plants inspected at seven days.
b) Injured and Non-injured leaves of aloe plants inspected at fourteen days.
c) PDA disks without inocula (8mm).

were soft, dry and wrinkled. Slight presence of white creamish mycelium only on the inoculated agar and not on the infected leaf surface. Underside of infected leaves had a slight presence of white mycelium with orange sporodochia. Upper and lower non inoculated leaves are not affected and there was no oozing.

Severe symptoms on infected aloe plants when continued to be kept in moist conditions for 14 days (Table 2).

Aloe arborescens - Presence of wet rotting lesions with ooze, infected leaves wilts. Presence of orange sprodochia at the base of infected leaves with abundance of aerial mycelium on inoculated region and base of infected leaves. Non-injured leaves also are infected. Blackish color around shrunken lesions and yellow to brownish color towards the edges of the lesions with yellow and white aerial mycelium.

Aloe compacta- Wet rotting lesions with ooze on severely infected leaves. Slight presence of yellow and white mycelium on up and underside of infected leaves. Purplish color around inoculated region and turning brownish in severe stages. Non-injured leaves also infected leading to lodging and wilting of entire plant.

Aloe vera and *A. ibitensia*- Wet rotting lesions with ooze on severely infected leaves. Non-injured leaves also infected with and abundance of white aerial mycelium on its upper and under sides. Infected leaves turn light to dark brown in color, water soaked with abundance of white mycelium growth leading to complete plant death.

Aloe capittata- Presence of ooze on wet rotting lesions. Infected leaves turn purplish color around base of plant and brownish towards the tip. Non-injured leaves towards the tip of plant become detached from the stem, lodges and wilts leading to complete plant death.. Inoculated region is dark black in color and

Table 3. AoEFg 01 inoculated on injured leaves and roots of *A. arborescens* and *A. vera* after 7 days.

	Inoculum		
Aloe sp. treated	Spore suspensiona AoEFg 01	Mycelium disks (8mm) AoEFg 01	Sterilized water (Control)
A. arborescens			
Leaves	+++	+++	-
Roots	-	N.T	-
A. vera			
Leaves	+++	+++	-
Roots	-	N.T	-

- (No symptom), + (mild symptom), ++ (moderate symptom), and +++ (severe symptom).
a) Spore conidial suspension (1 x10^6 conidial/ml)

have a slight presence of white mycelium on the upper and underside of infected leaves.

Aloe nobilis- Infected leaves are dry, wrinkled and soft. Infected leaves become brown, black and yellow in color with a presence of white creamish mycelium on upper and underside. Base of aloe stem is also infected, and non-injured lower leaves are severe infected. Mother plant together with young aloe stolons growing on the sides become infected, lodge, detached, wilt and die.

AoEFg 01 isolate was only pathogenic to the injured leaves of A. arborescens and A. vera and not to the injured roots (Table 3).

3.3 *Optimum growth temperature*

Isolate AoEFg 01 grew at a temperature range between 10-35°C with an optimum temperature of 28°C and an average growth rate of 6.54mm/day (Fig 1). There was no growth observed at 5°C and 40°C. Mycelium growth was observed when 5°C PDA dishes were placed at 25°C room temperature, thus indicating that the Fusarium sp. is able to survive in hash cold conditions.

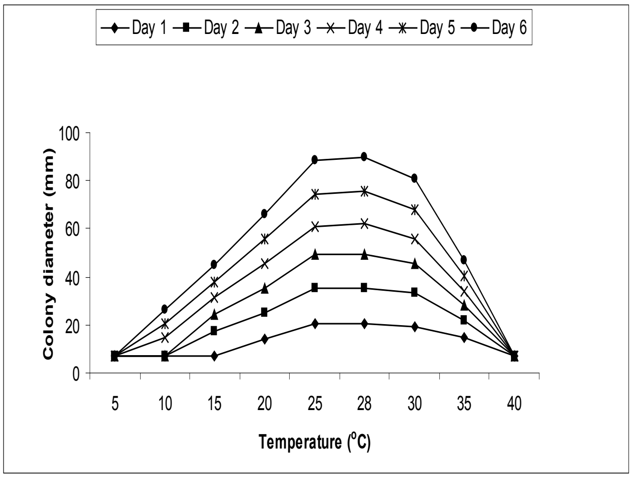

Figure 1. Mycelial colony growth of AoEFg 01 isolate on PDA at different temperatures for 6 days.

3.4 *Morphological characters*

AoEFg 01 had a white and purple spongy colored like aerial mycelium and it was abundantly produced on PDA at 20-35°C forming irregular patterns over the surface of the agar (Fig. 2).

On Oat meal agar, incubated in the dark at 25°C, AoEFg 01 produced pale orange, reddish, purplish and whitish aerial mycelium with yellow, orange to red pigments in the agar. Under continuous Black light, AoEFg 01 on OA and PDA produced orange thin cottony aerial mycelium. There was also the presence of a thick white irregular mycelium growth on the OA plates. AoEFg 01 grown on OA and PDA were odorless.

On SNA, both micro and macro conidia was abundant. AoEFg 01 on SNA near BLB had a flat white aerial mycelium with no pigmentation. Sporodochia absent in SNA, but was observed and present on CLA under contiuous BLB and was yellow to orange in color. Phialide morphology on SNA and CLA were monophialidic and can be branched and unbranched.

Micro conidia were abundant in aerial mycelium, oval, hyaline, obovoid to elliptical with a truncate base shape. Non septatte conidia, 9.5 x 3.1 µm (7.6-12.2 x 2.3-4) µm in size. One septate conidia, two-celled oval and allantoid, 18.2 x 3.4 µm (14.3-22.3 x 2.8-4.5) µm. Two septate conidia, fusiform 29.9 x 3.1 µm (22-27.6 x 2.1-3-8) µm.

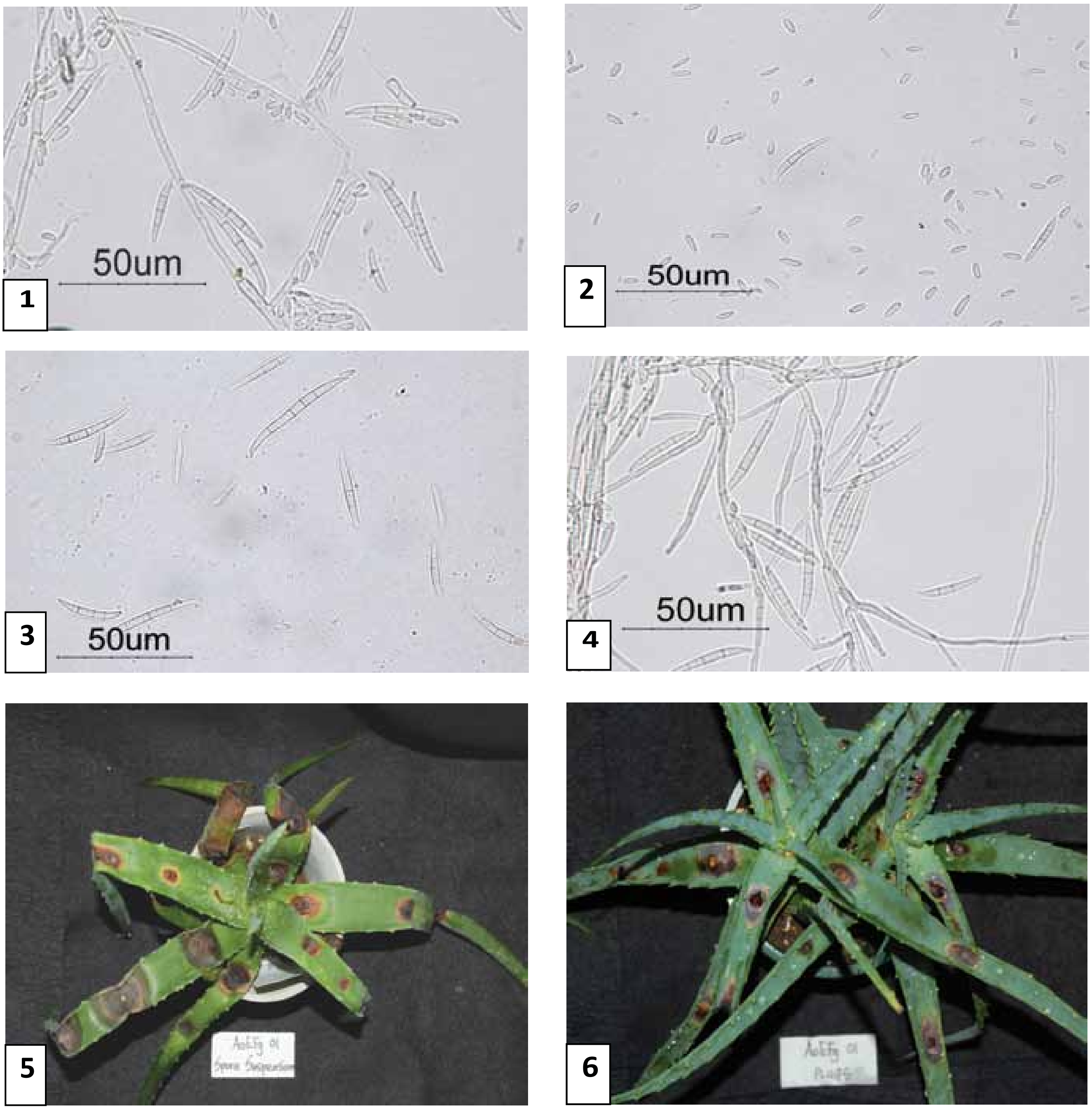

Figure 2. 1 – 4 Morphology of *Fusarium* sp. AoEFg 01 fungal strain isolated from infected *A. aborescens* and grown on SNA for 2-3 weeks.

1, 3 and 4. *Macroconidia* developing from long and short *Monophialides.*
2. Microconidia and Macroconidia on aerial mycelium.
5. Symptoms on injured *A. vera,* 7 days after AoEFg 01 Spore inoculation.
6. Symptoms on injured *A. aborescens*, 7 days after AoEFg 01 (8mm) disk inoculation.

Sporodochial conidophores were abundant in 3-septate macro conidia. Macroconidia were falcate, cylindrical, curved on the dorsal side and slightly straight on the inside. Macro conidia were hyaline, with a slightly pointed and curved apical cell with a distinct foot cell on 3-5 septate, Abundance of 3-septate conidia 44 x 3.9 µm (34-49.6 x 3.3-4.3) µm. Four septate conidia, were similar to the 3-septate conidia but longer, 54 x 4.2 µm (42.8-59 x 3.6-4.7) µm. Although yellow pigmentation was not evident on PDA, on minimal media yellow pigmentation was quickly observed after five days at 25 degrees in complete darkness. Yellow pigmentation in the agar is a common and convenient but not absolute characteristic of this species (Klittich *et al.* 1997).

There was no chlamydospore formation when AoEFg 01 were inoculated on Soil Agar and kept at 25 degrees for 2-3 weeks.

4.0 DISCUSSION

At present there are four fungal diseases of Aloe reported in Japan; Phytophthora Rots of *Aloe dichotoma* and *Anemone coronaria* caused by *Phytophthora nicotianae* (Uematsu *et al.* 1995), foot rot caused by *F. dimerum* Penzig var. dimerum (Motohashi *et al.* 1998), purple spot caused by *Fusarium phyllophilum* Nirenberg and O`Donnell (Kishi *et al.* 1999), crown and root rot caused by *F. oxysporum* Schlecht. (Alfieri *et al.* 1984) and aloe ring spot caused by *Haematonectria haematococca* (Berk. & Broome) Samuels & Nirenberg (Hirooka *et al.* 2006). To date, there is no record of *F. thapsinum* causing disease on the genus *Aloe* (Phytopathological Society of Japan 2000; Farr *et al.* 1989). Thus the present pathogenic fungus *F. thapsinum,* pathogenic to Aloe is considered a new record.

Fusarium moniliforme, teleomorph *Gibberella fujikuroi* is morphologically similar (mating population A) to *F. thapsinum* and its teleomorph *Gibberella thapsina.* The two groups can be distinguished based on mycotoxins produce, isozyme polymorphism, electrophoretic karyotype, benomyl sensitivity, and the differences in the sequence of the internal transcribed spacer (ITS) region of the ribosomal DNA repeat (Klittich *et al.* 1997). The isolate differed from *F. phyllophilum* in that it was pathogenic to all six *Aloe* sp. inoculated whereas *F. phyllophilum* was only pathogenic to *A. arborescens* (Kishi *et al.* 1999). Also Kishi *et al.* 1999 stated that the *F. phyllophilum* was pathogenic on wounded and non wounded *A. arborescens* whereas the present isolate was pathogenic only to wounded *Aloe* sp. The optimum temperature was 25 degrees in seven days for *F. phyllophilum* (Kishi *et al.* 1999), whereas its 28 degrees for the present isolate in six days.

F. andiyazi is also morphologically similar to *F. thapsinum,* but differed in that it produces pseduochlamydospores while *F. thapsinum* doesn't (Marasas *et al.* 2001). Klittich *et al.* 1997 also stated that *F. thapsinum* although morphologically similar to *F. prolifeartum,* produced only monophialidies branched and unbranched which is different from *F. prolifeartum* which produces both monophialides and polyphialides.

The representative isolate AoEFg 01 doesn't produce chlamydospores. AoEFg 01 produces yellow pigmentation on minimal media and branched and unbranched monophialides. These morphological features combined with the phylogenetic analysis greatly support AoEFg 01 isolate to be *F. thapsinum.*

This is the first record ever of *F. thapsinum* to be found pathogenic to *Aloe* species in Japan and the world.

The present study indicates that a new disease on Aloe species and named brown spot rot of aloe was caused by *Fusarium thapsinum.*

ACKNOWLEDGEMENTS

The author thanks Dr. T. Arie and Graduate student Mr. Keigo Inami, Tokyo University of Agriculture and Technology, Fuchu Campus, for the use of the TUAT Plant pathology laboratory and their tremendous help in DNA sequencing.

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RESEARCH PAPER

Bacterial and Enterobacterial load of pond water and aquacultured tilapia, *Oreochromis nilotics* (L.), sourced from two major farms in Fiji

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ABSTRACT

Total bacterial load and total Enterobacteriaceae in pond water, gills, skin and gastro-intestinal tract of aquacultured tilapia, *Oreochromis niloticus* (Linnaeus, 1758), raised at Navua Prawn Farm (NPF) and Naduruloulou Research Station (NRS) was estimated. The aerobic mesophilic counts of bacteria in pond water were estimated to be 6.7 x 103 cfu/mL and 2.98 x 105 cfu/mL at NPF and NRS respectively. The Total Enterobacteriaceae Counts in pond water were estimated as 6.40 x 102 cfu/mL and 1.33 x 104 cfu/mL at NPF and NRS respectively. The aerobic mesophilic counts and Total Enterobacteriaceae counts were much higher in gills, gastro-intestinal tract and on skin of tilapia cultured at NRS than at NPF. The purged fish sample from NRS showed much lower Total Enterobacteriaceae and aerobic mesophilic counts. The tilapia pond at NRS may have been contaminated by the daily influx of duck excreta from a cage housed just above the pond for fertilization purpose. The infrequent water change of tilapia pond further led to increased bacterial levels. The daily water change of ponds at NPF contributed to hygienic culture conditions. Proper purging of tilapia is recommended to extend storage life of tilapia and tilapia products and to prevent spread of food-borne diseases.

Keywords: Tilapia, bacterial load, Enterobacteriaceae, pond water, excreta-fertilization, storage life.

1.0 INTRODUCTION

Tilapia has been domesticated in Fiji for human consumption since 1950's (Holmes 1954). Since then the consumption of fresh tilapia is increasing and culture of tilapia is slowly moving towards commercialization. The production volume and value of tilapia has increased by 12.5% from 2007 (Fisheries Department 2008). As products from tilapia aquaculture increase and current sales outlets saturate, attempts are now being made to develop post-harvest processing and value-adding of tilapia to provide additional avenues for marketing of tilapia (Natasha *et al*. 2013). The quality and storage life of tilapia and tilapia products would be highly dependent on the bacterial load of fish and the culture environment. However, there is a dearth of information on the bacterial load in tilapia cultured in Fiji.

Fish production in excreta-fertilized fish ponds is a common practice in Fiji. Chicken manure is broadcast over the pond bottom and/or in a sack floated in the pond to initiate fertilization (Nandlal and Pickering 2004). The fertilizer encourages the growth of plankton that provides natural food for the tilapia and is a relatively in-expensive way to provide food for the fish. Sometimes integrated farming with livestock is also employed with tilapia farming. This system of farming may introduce enteric bacteria into the water system. The enteric bacteria or Enterobacteriaceae is a large family of Gram-negative bacteria that includes many harmless symbionts and pathogens such as Salmonella, *Escherichia coli* (*E. coli*), Yersinia pestis, Klebsiella, Shigella, Proteus, Enterobacter, Serratia, and Citrobacter (Harrigan 1998). While these bacteria are not normal inhabitant of fish flora, they have been isolated from the stomach and intestines of fish (Guzman *et al.* 2004). Freshwater fish and their aquatic environment are known to harbour human and animal pathogenic bacteria (Leung *et al*. 1992). The pathogenic bacteria of the Enterobacteriaceae family may cause contamination of fish resulting in poor quality of fish and fishery products and faster spoilage upon harvest (Kaneko 1971).

To evaluate the sanitary conditions of ponds, either of the indicator pathogenic bacteria; *E. coli*, Faecal Coliforms or Total Enterobacteriaceae, are considered. Some workers have investigated the microbial loading of tilapia reared in brackish water ponds (Al-Harbi and Uddin 2005), freshwater ponds (Al-Harbi 2003), sewage and wastewater-fed ponds (Balasubramanium *et al.* 1992) but microbial loading of tilapias reared in Fiji are unknown. It is important to know the bacterial load on tilapia in order to market tilapia either as live fish or as processed value-added products which are of highest quality possible.

The present study was designed to determine the total bacterial and total Enterobacteriaceae counts in pond water, skin, gills and gastro-intestinal tract of cultured tilapia from two major farms in Fiji; Naduruloulou Aquaculture Research Station (NRS) in Nausori and Navua Prawn Farm (NPF) in Navua , Fiji.

2.0 MATERIALS AND METHODS

The bacterial load of pond water and tilapia project was a preliminary work conducted prior to the processing of value-added products from tilapia as part of a larger study on establishing post-harvest processing mechanisms for potential commercialisation of tilapia in Fiji.

2.1 *Description of the ponds*

Naduruloulou Research Station (NRS) was established in 1975 and is located 7km to the North from Nausori Town, along the Rewa River. Water to the pool site is supplied from the nearby Rewa River by continuous pumping. Tilapia is the only species in the pond under study. This pond is used for grow-out phase and fish is harvested for sale at the end of the grow-out period. A cage is housed just over the pond for rearing ducks. The duck excreta are used for fertilization of the pond water. The depth of pond is ca. 1.5m and the size is on average 1,500m^2. Water change is done once a month and is partially drained out during rainy days to prevent flooding which may cause loss of fish.

The Navua Prawn Farm (NPF) is Fiji's largest commercial farm, operated by the then Dairy Farm Fiji Aquaculture Unit, located in Navua along the Navua River. It was established in 2005 and its main commodities are prawns and tilapia. Water to the pond site is supplied from the nearby Navua River. Tilapia is the only fish species in the pond under study. This pond is used for grow-out phase and fish is harvested for sale at the end of the grow-out period. Fertilization is done by broadcasting chicken manure packed in cotton sacks over pond water once a month. The depth of this pond is ca. 1.5m and the pond size is on average 1,500m^2.

2.2 *Water and Tilapia Sample collection*

Test case ponds in each farm sites were sampled separately over a two day period in the month of September, 2012. All sampling was done between 0830 to 1030 h. Sterilized glass sample bottles (250 mL) were left capped until used for the collection of pond water samples in triplicates from eight different sites within the pond. Water samples were collected in triplicates 15-20cm below the water surface to avoid surface contamination.

Twenty tilapias were randomly harvested by a cast net from the test case ponds and were placed individually in UV pre-sterilized bags before being placed in sterilized cooler chests containing ice. The temperature inside the cooler chests was 3°C. Direct contact of the fish samples with the ice was avoided to ensure maximal survival and recovery of bacteria. Aseptic procedures were strictly followed during collection, transportation and analysis of fish samples.

All samples were transported to the University of the South Pacific Microbiology Laboratory at the Marine Campus in Laucala Bay, Fiji, within 30 - 50 minutes. Microbial examinations were carried out immediately.

2.3 *Water quality analyses*

The pH, temperature and dissolved oxygen (DO) was measured with a YSI meter and turbidity was measured with a secchi disk. All water parameters were measured in triplicates at the same sites where water samples were collected within the pond.

2.4 *Sample preparation*

Pond water samples: After preparing a composite sample, five-fold dilutions were made using 0.1 % peptone water and 1 ml from each dilution was transferred to petri dishes and Petrifilm™ Enterobacteriacea films. Plates were poured using tempered Plate Count Agar (PCA) maintained at 46°C. The content of the plates were mixed thoroughly and allowed to set. After medium had set, plates were inverted and were incubated at the following temperatures as outlined by APHA (2005):

a) 30 ± 0.5 °C for 72 ± 3 h for Aerobic Mesophilic Count
b) 35 ± 0.5 °C for 48 ± 3 h for Total Heterotrophic Count
c) 35 ± 0.5 °C for 24 ± 3 h for Total Enterobacteriacea Count

Water samples were also sent to Institute of Applied Science (IAS) Microbiology Laboratory at the University of the South Pacific, Marine Campus, in Laucala Bay, Fiji for confirmation of *Vibrio* spp. where procedures outlined by APHA (2005) were used.

Microbial counts were expressed as $\log_{10}$ colony forming units (cfu) per mL of sample.

Fish samples: In the laboratory, each fish sample was placed in a sterile tray disinfected with 75 % ethyl alcohol. Skin surface, gills and the gastro-intestinal regions were used to test for bacterial load. These regions were swabbed separately with sterile 3M™ environmental quick swabs (Thermofisher, NZ). A sterile template was used to swab skin surface area of 25 cm^2 whereas the gills (opened aseptically using sterile forceps) were swabbed from both sides. The gastro-intestinal region was swabbed by making an insertion in the abdomen using a sterile scalpel.

The swab was placed in 100 mL Peptone Saline Water and mixed thoroughly by rotating the bottle on the table in circular motion for at least a minute. Five-fold dilutions were prepared after 30 minutes of resuscitation at room temperature and samples were inoculated on Petrifilms for the following:

a. 35 ± 0.5°C for 48 ± 3 h for Aerobic Mesophilic Count
b. 35 ± 0.5°C for 24 ± 3 h for Total Enterobacteriacea Count

Fish samples were also sent to Institute of Applied Science Microbiology Laboratory at the University of the South Pacific, Marine Campus, in Laucala Bay, Fiji for confirmation of *Vibrio* spp. where procedures outlined by APHA (2005) were used.

2.5 *Data Analysis*

Means and standard deviations (SD) were calculated on version 18 of SPSS. Independent T-test was performed on the same statistical software to determine significant difference

Table 1. Mean (±SD) physicochemical parameters of pond culture water at Naduruloulou Research Station and Navua Prawn Farm.

Pond Site	Dissolved Oxygen (mg/L)	Temperature (°C)	pH	Turbidity (cm)	Water colour
Navua Prawn Farm	3.88 ± 2.25^{a}	26.0 ± 0.47^{b}	6.60 ± 0.03^{c}	13.25 ± 1.98^{d}	Light brown
Naduruloulou Research Station	2.01 ± 1.16^{a}	25.5 ± 0.35^{b}	7.89 ± 0.06^{c}	9.54 ± 0.87^{d}	Medium Brown

Means followed by the same letter in the same column do not differ significantly by Independent T-test (P < 0.05). n = 24

Table 2. Microbial load of pond culture water from Naduruloulou Research Station and Navua Prawn Farm.

Type of Count	Navua Prawn Farm (cfu/mL)	Naduruloulou Research Station (cfu/mL)
Aerobic Mesophilic Count	6.70×10^{3}	2.98×10^{5}
Heterophic Count	6.97×10^{3}	7.00×10^{4}
Total *Enterobacteriacea* Count	6.40×10^{2}	1.33×10^{4}
Vibrio spp.	ND	ND

(a = 0.05) between the physiochemical parameters of pond water for the two farms under study.

3.0 RESULTS

3.1 *Physicochemical parameters of pond water at Naduruloulou Research Station and Navua Prawn Farm*

The Dissolved Oxygen (DO) of pond water at NPF was higher than NRS, while not much variation in the water temperatures between the study farms was observed (Table 1). The pond water was slightly acidic at the NPF and slightly alkaline at the NRS. The colour of pond water at NPF was light brown with low turbidity level; while medium brown colour of pond water was observed at NRS with water turbid level beyond 9.54 cm (Table 1). No significant variation (Independent T-test; $P < 0.05$) was observed in the parameters between the two farms.

3.2 *Microbial load of pond water and fish*

The Aerobic Mesophilic Counts, Heterophic Counts and Total Enterobacteriacea Counts were much higher at NRS than at NPF (Table 2). Vibrio spp. was not detected.

The mean Aerobic Mesophilic Count and Total Enterobacteriaceae Count of gills, gastro-intestinal tract and skin of tilapia obtained from NPF, NRS and purged fish are shown in Table 3. Generally, higher counts of Aerobic Mesophilic Counts and Total Enterobacteriaceae Counts were observed on gills and skin of purged and unpurged tilapia fish from the two farms. Slightly lower counts were observed in the gastro-intestinal tract of fish from both farms (Table 3).

Fish samples brought from NPF showed highest AMC on gills followed by skin and gastro-intestinal tracts regions. Similar trend was also noted for TEC for these samples. Fish samples obtained from NRS showed high counts of AMC and TEC on skin followed by gills and gastro-intestinal tract. Marked difference in AMC and TEC was observed between the samples obtained from NRS and NPF. Higher counts of aerobic mesophilic colonies and total Enterobacteriaceae colonies were recorded for samples obtained from NRS (Table 3).

Purged samples showed lower counts of AMC and TEC than samples from NRS and NPF. The gastro-intestinal tract of purged samples had higher counts of AMC and TEC than gills and skin. No Enterobacterial colony formations were observed on skin samples of purged fish (Table 3).

Table 3. Microbial load of gills, gastro-intestinal tract and skin of tilapia sampled at Naduruloulou Research Station and Navua Prawn Farm.

Type of Count	Navua Prawn Farm (cfu/cm^2)	Naduruloulou Research Station (cfu/cm^2)	Purged Fish* (cfu/cm^2)
Gills			
Aerobic Mesophilic Count	9.77×10^3	1.64×10^8	1.64×10^2
Total *Enterobactericeae* Count	2.84×10^2	2.30×10^8	5.91×10^1
Gastro-intestinal tract			
Aerobic Mesophilic Count	2.22×10^3	1.58×10^8	8.05×10^2
Total *Enterobactericeae* Count	2.36×10^2	2.03×10^8	2.75×10^2
Skin			
Aerobic Mesophilic Count	6.09×10^3	7.20×10^8	1.30×10^2
Total *Enterobactericeae* Count	1.68×10^2	2.49×10^8	ND
Inner Flesh			
Aerobic Mesophilic Count	ND	ND	ND
Total *Enterobactericeae* Count	ND	ND	ND

*ND = Not detected. *Results for purged fish could not be obtained from NPF due to time constraints. Results displayed are for purged fish obtained from NRS only.*

4.0 DISCUSSION

The physiochemical parameters of the two tilapia farms studied were not within the range suitable for tilapia culture in the Pacific as per the guidelines provided by Nandlal and Pickering (2004). The dissolved oxygen (DO) was lower at NRS (2.01 ± 1.16 mg/L) than the recommended level of > 3 mg/L. Oxygen dissolves in water from air, by the action of waves created by wind and by addition of new water (Nandlal and Pickering 2004), photosynthetic oxygen generation and total plankton respiration (Smith and Piedrahita 1988).

The amount of plankton (zooplankton and phytoplankton) and algae in the water also affects turbidity (Nandlal and Pickering 2004). The turbidity levels of both farms were also much lower than the recommended levels of 30 - 35cm (secchi disk reading) provided by Nandlal and Pickering (2004). While the turbidity level at NPF was lower than the recommended value, water change of ca. 50 % done every afternoon at NPF, led to lower turbidity and higher DO content than at NRS. More frequent water change at NRS fish ponds is warranted to improve dissolved oxygen level, turbidity and to also flush out bacteria.

The results showed high bacterial load in pond water at both the farms; 6.7 x 103 cfu/mL at NPF and 2.98 x 105 cfu/mL at NRS (Table 2). Similar results were obtained by Al-Harbi and Uddin (2003, 2005) in brackish water ponds for tilapia in Saudi Arabia. Al-Harbi and Uddin (2005) found the total viable count (TVC) as 1.4 ± 1.5 x 103 to 8.6 ± 2.7 x 103 cfu/mL in brackish water ponds for tilapia in Saudi Arabia, while Al-Harbi and Uddin (2003) reported a TVC in earthen tilapia ponds of 5.6 ± 0.8 x 103 to 2.4 ± 1.2 x 104 cfu/mL at temperatures in the range of 27 – 28 °C. Our study also showed similar results for NPF but not for NRS.

The microbial load reported for NRS is relatively higher than as reported by the supra-literature. The continuous daily influx of duck excreta result in increase of bacterial numbers for decomposition of excreta. The nutrients from excreta also support the growth of plankton and other micro-organisms which are consumed by the fish with little additional feeding taking place (Balasubramanium *et al.* 1992). The combined effects of the high ambient temperature of the pond water, which was close to optimum for many mesophilic bacteria in natural systems (Newaj-Fyzul *et al.* 2008), and nutrients from excreta may have caused the high bacterial load in the tilapia pond at NRS. Animal excreta also introduce Enterobacteriaceae into the ponds. Sources of Enterobacteriaceae into tilapia ponds could be varied; for example the initial Enterobacteriaceae level in the water pumped in from the river and animal excreta run-off from land during rain; however, duck excreta used for fertilization purpose appears to be the most obvious contaminant.

NPF had lower bacterial counts than NRS (Table 2). The daily water change of ca. 50% flushes out excessive bacterial growth and also maintains ideal culture conditions for rearing tilapia. The findings of this study agree with Pullela *et al.* (2000) who demonstrated lower faecal coliform count in tilapia reared in a re-circulating system than tilapia cultured in a non-circulating system.

NPF had lower bacterial load fish and in the pond water than NRS. Al-Harbi and Uddin (2004) reported the intestinal bacterial load of fresh water tilapia in Saudi Arabia as 6.8 x 106 to 7.5 x 107 cfu/g. Al-Harbi and Uddin (2005) reported 8.7 x 105 to 2.1 x 106 cfu/g in gills of tilapia reared in brackish water while 7.1 x 105 to 8.7 x 106 cfu/g was reported in gills of hybrid tilapia reared in earthen ponds in Saudi Arabia (Al-Harbi and Uddin 2003). Al-Harbi and Uddin (2003, 2004 & 2005) reported higher microbial load in gills and intestine than the corresponding pond environment. Intestinal microflora of fish or contamination of fish as a result of enteric bacteria of human or animal origin has been responsible for various food spoilages (Cahill 1990).

The incidence of high bacterial load in gills and intestine of fish than in pond water has been stipulated to be due to high metabolic activity of fish associated with increased feeding rates at higher temperatures (Al-Harbi and Uddin 2004). On the contrary, results of this study show that bacterial load of pond water and on fish tissues to be almost similar at a temperature of 25 - 26 °C.

Intestinal microflora of fish has also been shown to be influenced by the microflora of the ingested feeds (Savas *et al.* 2005). It has also been mentioned that the intestinal flora composition of fish is related to the degree of bacteriological contamination of the food consumed (Pal and Gupta, 1992; Savas *et al.* 2005). Tilapia is a voracious feeder and mainly feeds on the detritus organic matter. Both free-living and particle bound bacteria are usually associated with particulate organic matter and are consumed by fishes such as carp and tilapia (Savas *et al.* 2005). The microflora of pelletized feed was not investigated due to time and budget constraints; however, it would be worthwhile to investigate the microbial load of pelletized feed used for feeding tilapia.

Purged fish from NRS, on the other hand, showed considerable reduction in Aerobic Mesophilic Count and Total Enterobacteriaceae count in gills, gastro-intestinal tract and on the skin of tilapia. It was in depurated fish, that higher bacterial and enterobacterial load was found in gastro-intestinal tract than on gills and skin. The higher count of bacterial load in the gastro-intestinal tract could be due to fish being purged for only two hours. Balasubramanium *et al.* (1992) reported that the bacterial reduction in the gut content of different species reared in wastewater fed ponds ranged between 63 and 78 % after 20 days of depuration. Thus, longer hours of purging may be required to further decrease the bacterial load in fish.

Studies on the microbiological quality of fish raised in wastewater-fed fishponds have indicated that faecal bacteria may penetrate the fish flesh when fish is grown in highly polluted water, whereas other studies found no or little penetration of micro-organisms in aquaculture environments in which the fish were not stressed (Cam *et al.* 2007). The present study showed no penetration of micro-organisms into the fish flesh which indicates that the aquatic environment may not be highly polluted as may occur in wastewater-fed ponds. This study has re-affirmed that bacterial flora of fish reveals the bacteriological conditions of the water where fish inhabit. High bacterial and enterobacterial load of pond water led to establishment of these bacteria in fish gills, skin and gastro-intestinal tract. Normally, to determine the sanitation and hygiene of aquaculture ponds, counts of faecal coliforms and/or *E. coli* are used. The World Health Organization's guideline for fishpond state that water should have a faecal coliform count of $\leq$ 1000 per 100 mL (WHO, 1989). While the counts of faecal coliforms or *E. coli* were not estimated separately, the current levels of Enterobacteriaceae at NRS deem the culture conditions as unhygienic.

This has implications for post-harvest quality and shelf-life as contamination may affect the storage life and quality of the fishery products. Contamination may result from rupturing of the fish intestine during processing and/or from inadequate washing. For future commercialization of tilapia in Fiji, this data is required for the development of preventive measures to safe guard against infectious agents that could cause diseases and post-harvest losses. Aquatic microorganisms not only influence the water quality but are also known to be closely associated with the physiological status of the fish, disease and postharvest quality. It is recommended that tilapia farmers practice proper purging of tilapia before sale and proper sanitation and hygiene to be maintained during handling of fish to extend storage life of fish and fishery products and to prevent spread of infection to humans. It is important that initial microbial load of fish is at safe levels in order to prevent contamination and food-borne diseases.

ACKNOWLEDGEMENT

The study was conducted within the Pacific Agribusiness Research for Development Initiative (PARDI) project "Value adding and supply chain development for fisheries and aquaculture products in Fiji, Samoa and Tonga" funded by the Australian Centre for International Agricultural Research (ACIAR). The first author was awarded an ACIAR-USP scholarship from the Australian Government to study at the University of the South Pacific (USP). The support of ACIAR, USP, staff of Navua Prawn Farm, and Fisheries Department are greatly acknowledged.

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RESEARCH PAPER

Promoting *Santalum yasi* Seeman (Sandalwood or *Yasi*) in agroforestry systems to reverse agrodeforestation in Fiji

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ABSTRACT

The people of Fiji had relied on agroforestry since the time early settlers arrived here. Increase in food requirement, urbanization, decrease in intentional tree planting habits among the people due to change in mindsets has contributed to conversions of agroforest tree dominated landscapes. It has led to agrodeforestation threatening flows of important ecosystems good and services. Promotion of a socio-economically, historically and culturally valuable agroforestry tree species by compulsorily integrating in agroforestry systems will perhaps pave a way forward to reverse agrodeforestation. *Santalum yasi* is such a species for Fiji. During 2012 and 2013 through this study attempt was made to observe existence of suitable host for yasi in different farms, its relative importance value and also farmers to understand whether there exist suitable host and soil hydraulic conditions for this species. Visits was conducted during 2012 and 2013 in randomly selected farms that include private owned farm, institutional owned farm i.e. FNU's farm at Navua and *mataqali* owned farmland in different areas of Viti Levu. The study revealed that suitable host for yasi exists in all the farms. Soil hydraulic conditions indicated that almost same irrigational plan can be developed for yasi in all the farms. The study urges to massively promote *S. yasi* as a highly desirable agroforestry tree species in agroforestry systems in Fiji to reverse agrodeforestation.

Keywords: Agroforestry systems, Pacific Island, Sandalwood, Sustainable livelihood, *Santalum yasi.*

1.0 INTRODUCTION

Agroforestry, the intentional growing of trees and shrubs in combination with crops or forage (USDA 2013) has been in practice since the time early settlers arrived in Fiji (Clarke and Thaman 1993). It played a vital role in sustaining the *vanua* an *iTaukei* term for land that incorporates the interrelationship between the physical, social and cultural dimensions (Ravuvu 1983). Traditionally all trees on community land here were taken to be integral to the whole agricultural system and to human welfare (Clarke and Thaman 1993).

Farmers planted and or maintained different agroforestry tree species traditionally in agroforestry systems for sustaining food and other requirements (Arnold and Deewes 1999). Agroforestry systems vary among the communities like in other parts of the tropics since they have evolved in response to soil, social and ethological conditions (Ruthenberg 1976). The indigenous management of agroforestry systems evolved through trial and errors over a long period like in other tropical areas of the world (Rai and Proctor 1986).

Fiji, endowed with forest, fish, minerals and biodiversity, is one of the most developed of the large pacific island economies though still with a large subsistence sector (Raitamata 2011). Of the total area of Fiji's 18,270 sq. kms only 9.17% is arable (CIA 2011). The two major islands mainly Viti Levu and Vanua Levu cover more than 87% of the total land area. Higher demand for food resulting in conversion of trees dominated landscapes to agriculture along with other worldwide deforestation process like urbanization, industrialization, commercial logging, increase population (Clarke and Thaman 1993) exerts pressure on traditional agroforestry systems.

Agroforestry trees that were intentionally planted in the past are now much less frequently planted by the younger generations (Clarke and Thaman 1993). Gradual changes in mindset for not compulsorily planting of socio-economical and culturally important agroforestry trees in their land and instead depend on imported fast foods, etc. to meet the requirements exists in Fiji and other pacific islands. It lead to lack of interest in plantation of agroforest tree species and the great variety of useful tree species in gardens, villages and towns suffers depletion 'agrodeforestation' (Clarke and Thaman 1993). Thaman (1982) emphasized that continued agrodeforestation will result in reduced living standards and conditions. Apart from great biodiversity losses there will also be drastic disturbances in smooth flow of ecosystem goods and services. Little or no official recognition of agrodeforestation in Fiji unlike the case of deforestation might be the reason for few attempts to reverse the agrodeforestation trend (Thaman 1989). There is a strong need to promote highly valuable and economically remunerative agroforestry tree species to reverse in agrodeforestation.

Santalum yasi Seeman (Sandalwood or yasi) an important agroforestry species is a small shrub or tree often attaining a height of 5 to 12 m at maturity possesses a considerable economic potential. It occurs naturally in open, dry forest and in woodland communities. It prefer warm to hot, low land, sub-humid or wet dry tropics. It cannot persist in moist dense forest types due to its poor tolerance of high shade levels. It grows well from 0 to 1,200 masl (Thomson 2006). Apart from being economically highly remunerative with strong international demand for its high-value aromatic heartwood oil, *S.yasi* have a strong role in the society of Fiji.

Traditionally the Chiefs in Fiji are anointed with sandalwood oil during *'kena vagunuvi e dua na Turaga buli'* meaning traditional installation ceremony. The trade in sandalwood, including of *S. yasi,* from the Pacific Islands has been documented in Thomson and Doran (2011) and Thomson (2013). Strict control on harvesting of *Santalum album* in India, the largest producer of sandalwood oil in the world opens up the scope for renewing *S. yasi* trade in Fiji (Rakoko 2013). In spite of possessing such immense importance for the people of Fiji, this species have a long history of extensive harvesting for its aromatic oil that may have threatened this species to extinction (Huish *et al.* 2010). Taking into consideration the high demand of *S. yasi*, its place in the society and its threats this species can perhaps be widely promoted as a agroforest tree species for Fiji.

This study is an attempt to understand whether suitable host and soil hydraulic conditions exist in the farms for promotion of yasi as a compulsory agroforestry tree species to reverse agrodeforestation in Fiji.

2.0 MATERIALS AND METHODS

2.1 *Field visit sites.*

Field visits were conducted during 2012 and 2013 in Viti Levu to Navua, Galoa, Draiba, Legalega, Ba, Rakiraki and Sote. These were randomly selected to include private owned farm, institutional owned farm i.e. FNU's farm at Navua and mataqali owned farmland. The reason behind selecting such mixture of farms is to get a fair representation of suitable *S. yasi* host and soil conditions under different management conditions.

2.2 *Suitable host and its relative importance.*

Suitable yasi host species as recommended by Jiko (2000) and Thomson (2006) were reviewed and occurrence of any of the species in each of the visited farms was recorded.

2.3 *Relative importance value of host species.*

The method described by Clarke and Thaman (1993) with slight modifications is adopted to find out the relative importance value of the host species. Based on occurrence of each suitable yasi host species on 81-100%, 61-80%, 41-60%, 21-40% and 1-20% of the visited farms, corresponding relative importance value of 5, 4, 3, 2 and 1, respectively was assigned.

2.4 *Soil hydraulic properties*

Soil texture was calculated for each farm and soil hydraulic properties namely wilting point, field capacity and available water were estimated following Saxton *et al*. (1986).

3.0 RESULTS AND DISCUSSION

3.1 *Existence of suitable yasi host.*

There were 16 suitable *S. yasi* host tree species observed in the farms during the study (Table 1). These trees were either planted and or intentionally left to grow in the farm. Suitability of these species as probable yasi host is reported by Huish (2009). Maximum host species for yasi were observed in the farmer's field at Rakiraki while only one suitable host species for *S. yasi* could be observed at the Legalega farm. The study clearly indicated that suitable hosts for yasi occurred in all the sites visited during the study.

The challenges of successfully raising *S. yasi* which have a semi-parasitic trophic mode, along with silvicultural and agroforestry best practices, have been documented by Thomson *et al.* (2000), Thomson (2006) and Thomson *et al.* (2011). Existence of suitable *S. yasi* host in all the farms studied indicates the fact that yasi can perhaps be comfortably included as a compulsory agroforestry species in agroforestry systems.

3.2 *Relative importance of suitable yasi host.*

About 25% of Yasi the host species in the studied area had a relative importance value of 3 (Table 2). The range of occurrence of these species in the studied farms is in between 42% to 57%. *Thespesia populnea* (L.) Sol. ex *Corrêa* exhibited a relative importance value of 2, it occurred in 29% of the farms. The remaining 69% of the host species occurred in 14% of the farms they had a relative importance value of 1. Uses of the species in meeting other requirements regulate the farmers' intention to keep these species in their farms.

3.3 *Soil hydraulic properties of the farms*

Ranges of soil hydraulic properties per cm^3 soil were - field capacity (0.25 to 0.33 cm^3 water), wilting point (0.15 to 0.18 cm^3 water) and available plant moisture (0.1 to 0.16 cm^3 water) (Table 3). Almost similar irrigation plan can be developed for this species across all the studied sites.

4.0 CONCLUSION

Agroforestry plays an important role for the people of Fiji by providing many goods and services. Conversions of agroforest tree dominated landscapes for food production, urbanization, change of mindsets among the people and not planting agroforest tree in their own lands are leading to agrodeforestation. Perhaps by promoting a socio-economically, historically and culturally valuable agroforestry tree species through compulsorily integrating in agroforestry systems will pave a way forward to reverse agrodeforestation. *Santalum yasi* is an important species for Fiji. There exist suitable host and soil hydraulic conditions in the farms studied for promoting yasi. Therefore this study urges to massively promote *S. yasi* as an agroforestry tree species in agroforestry systems in Fiji to reverse agrodeforestation.

Table 1. Suitable *Santalum yasi* host observed in different farms in Viti Levu during 2012 and 2013.

Farm	Recorded yasi host species	Local name	Family
Navua	*Gliricidia sepium* (Jacq.) Kunth. ex Walph	Bai ni cagi	Fabaceae
	Casuarina equisetifolia L.	Nokonoko	Casuarinaceae
	Pandanus tectorius Park.	Vadra	Pandanaceae
	Calophyllum vitiense Turril	Damanu	Chrysobalanaceae
	Fagraea gracilipes A. Gray.	Buabua	Loganiaceae
Galoa	*Hibiscus sp.* L.	Hibiscus	Malvaceae
	Fagraea gracilipes A. Gray.	Buabua	Loganiaceae
	Casuarina equisetifolia L.	Nokonoko	Casuarinaceae
	× *Citrofortunella microcarpa* (Bunge) Wijnands	Moli Kumquat	Rutaceae
Draiba	*Glyricidia sepium* (Jacq.) Kunth. ex Walph	Bai ni cagi	Fabaceae
	× *Citrofortunella microcarpa* (Bunge) Wijnands	Moli Kumquat	Rutaceae
	Thespesia populnea (L.) Sol. ex Corrêa	Mulomulo	Malvaceae
Legalega	*Gliricidia sepium* (Jacq.) Kunth. ex Walph	Bai ni cagi	Fabaceae
Ba	*Casuarina equisetifolia* L.	Nokonoko	Casuarinaceae
	Pinus caribaea Morelet	Pine	Pinaceae
	× *Citrofortunella microcarpa* (Bunge) Wijnands	Moli Kumquat	Rutaceae
Rakiraki	*Acacia richii* A. Gray	Qumu	Mimosaceae
	× *Citrofortunella microcarpa* (Bunge) Wijnands	Moli Kumquat	Rutaceae
	Thespesia populnea (L.) Sol. ex Corrêa	Mulomulo	Malvaceae
	Morinda citrifolia L.	Kura	Rubiaceae
	Storckiella vitiensis Seeman	Marasa	Caesalpiniaceae
	Hibiscus tiliaceus L.	Vau	Malvaceae
	Inocarpus fagifer (Parkinson) Fosberg	Ivi	Fabaceae
	Broussonetia papyrifera (L.) vent	Ai masi	Moraceae
Sote	*Gliricidia sepium* (Jacq.) Kunth. ex Walph	Bai ni cagi	Fabaceae
	Pometia pinnata J.R. Frost & G. Forst	Dawa	Sapindaceae
	Fagraea gracilipes A. Gray.	Buabua	Loganiaceae

Table 2. Relative importance value of suitable *Santalum yasi* host recorded in different farms in Viti Levu during 2012 and 2013.

Santalum yasi host species	Relative Importance Value
Gliricidia sepium (Jacq.) Kunth. ex Walph	3
× *Citrofortunella microcarpa* (Bunge) Wijnands	3
Casuarina equisetifolia L.	3
Fagraea gracilipes A. Gray.	3
Thespesia populnea (L.) Sol. ex Corrêa	2
Pandanus tectorius Park.	1
Calophyllum vitiense Turril	1
Hibiscus sp.	1
Pinus caribaea Morelet	1

Acacia richii A. Gray	1
Morinda citrifolia L.	1
Storckiella vitiensis Seeman	1
Hibiscus tiliaceus L.	1
Inocarpus fagifer (Parkinson) Fosberg	1
Broussonetia papyrifera (L.) vent	1
Pometia pinnata J.R. Frost & G. Forst	1

Table 3. Soil hydraulic properties of the studied sites in Viti Levu.

Farm	Wilting point (cm^3 water)	Field capacity (cm^3 water)	Plant available water (cm^3 water)
Navua	0.17	0.3	0.13
Galoa	0.15	0.25	0.1
Draiba	0.18	0.31	0.13
Legalega	0.15	0.31	0.16
Ba	0.18	0.33	0.15
Rakiraki	0.18	0.3	0.12
Sote	0.17	0.32	0.14

Results from table 2 also indicate that same yasi component can be incorporated in the agroforestry system of 14% to 57% of the farms. It might be helpful to deliver a visible impact that may generate interest across all levels for its large scale expansion in other areas of Fiji. Expansion of successful agroforestry systems have been reported by Place *et al.* (2012).

ACKNOWLEDGEMENTS

Sincere thanks to Dean College of Agriculture, Fisheries and Forestry (CAFF), Fiji National University for his valuable support and providing opportunity to visit Viti Levu and Vanua Levu. Thanks to all those farmers whose feedback helped immensely to complete this document. Comments from the Chief Editor of Fiji Agricultural Journal and Dr. Lex Thomson were helpful in improving this manuscript.

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RESEARCH PAPER

Galling of the Chinese Hibiscus (*Hibiscus rosa-sinensis L.*) in Samoa

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ABSTRACT

The ornamental Hibiscus (*Hibiscus rosa-sinensis* L.) is popular across the Pacific Islands. However, the cause of abnormal formation of galls is poorly understood in this species. In 2009, a field survey was carried-out in Upolu and Savaii Islands of Samoa, to determine the geographical distribution of gall infestation. In 2010 at Alafua Campus, a greenhouse pot experiment was conducted to assess 16 varieties to assess their susceptibility to galling. Results confirmed that the galling of the *H. rosa-sinensis* in Samoa was caused by the Eriophyid gall mite, *Aceria hibisci* (Nalepa). Galls were not present in Savaii. However, the geographical distribution of gall infestation in Upolu was severe, but the general damage was insignficant. It was observed that *A. hibisci* preferred red flowering varieties and also local varieties were more susceptible to galling than most of the exotic cultivars. *A. hibisci* caused galls mostly on vegetative buds and newly formed leaves, but also attacked fully developed leaves, petioles, calyces, unopened flowers, and young stems of *Hibiscus* species. The only alternate host plant for the *A. hibisci* identified in Samoa, was *Hibiscus schizopetalus* (Mast).

Key words: Chinese Hibiscus, *Hibiscus rosa-sinensis,* Eriophyid gall mite, *Aceria hibisci,* galls, Samoa.

1.0 INTRODUCTION

A popular flowering species, *Hibiscus rosa-sinensis* L., in the Pacific Islands has been haunted by galls for over a century. However, very little is known on the causes of galling. Galling of the *H. rosa-sinensis* was first reported from Fiji (Nalepa, 1906). It was later reported from New Guinea and the Solomon Islands (Keifer, 1946); New Caledonia and Wallis & Futuna (Williams & Watson, 1990); Hawaii (Hara *et al.,* 1996); Islands of Martinique (Flechtmann & Etienne, 2001); Cuba (De la Torre & Martinez, 2004); Australia (Carson & Gough, 2007); the Cook Islands, Tonga, Jamaica, Dominica, and Puerto Rico (Welbourn *et al.,* 2008); American Samoa, and Vanuatu. This similar galling was observed in Samoa but its cause has not been previously reported.

The galling of *H. rosa-sinensis* was caused by *Eriophyes hibisci* Nalepa (1906), which was later transferred to the genus *Aceria* (Keifer 1966); where the taxonomy became *Aceria hibisci* (Welbourn *et al.* 2008). *Aceria hibisci* is classified as an Eriophyid gall mite. Eriophyid mites were recognized as a taxon in the Acari (Seibold 1850); which belong to the class Arachnida and the family Eriophyoidae (Nalepa 1892). These mites are commonly known as ticks, rust mites, or gall mites (DMNC, nd).

Aceria hibisci have two types of life cycles: Simple – eggs, 1st nymph, hibernation, 2nd nymph, adult; Complex – which include two types of females, protogyne and deutogyne (DMNC, nd). The life cycle of *A. hibisci* seem to complete in less than three weeks (Hara *et al*., 1996). Welbourn *et al*.(2008) and Patton (2009) stated that the *A. hibisci* adult is about 0.2 mm long. Nymphs resemble adults but are smaller (Hara *et al*., 1996).

Jeppson *et al*. (1975), Hara *et al*. (1996), De la Torre and Martinez (2004), Carson and Gough (2007), Welbourn *et al*. (2008) reported that the *A. hibisci* prefer *H. rosa-sinensis* but may attack other species of the genus *Hibiscus.* In fact, *A. hibisci* was reported in Samoa on the *Hibiscus tiliaceus* L. (Nalepa 1909). However, certain insects (>2000), fungi, bacteria, and nematodes can also produce galls (Buss 2008), which hinders the direct conclusion that *A. hibisci* is the main causal agent of galling of *H. rosa-sinensis* in Samoa.

2.0 MATERIALS AND METHODS

2.1 *Cause of Galling*

Random leaf gall samples of *H. rosa-sinensis* were collected from four different geographical locations around Upolu (Aleisa, Vaigaga, Alafua, and Lotofaga). Each sample was placed in a specimen bottle containing 70% ethanol. The bottles were sealed, labelled, and Post mailed with an 'Insect identification permit' form to the Department of Primary Industries, Plant Health Services, New South Wales, Australia, in September, 2009. The specimens were identified to the species level by Dr. Danuta Knihinicki, Department of Primary Industries, Plant Health Services, New South Wales, Australia.

2.2 *Geographical survey*

The two main Islands of Samoa: Upolu and Savaii, was each divided into ten survey zones (Figure 1).

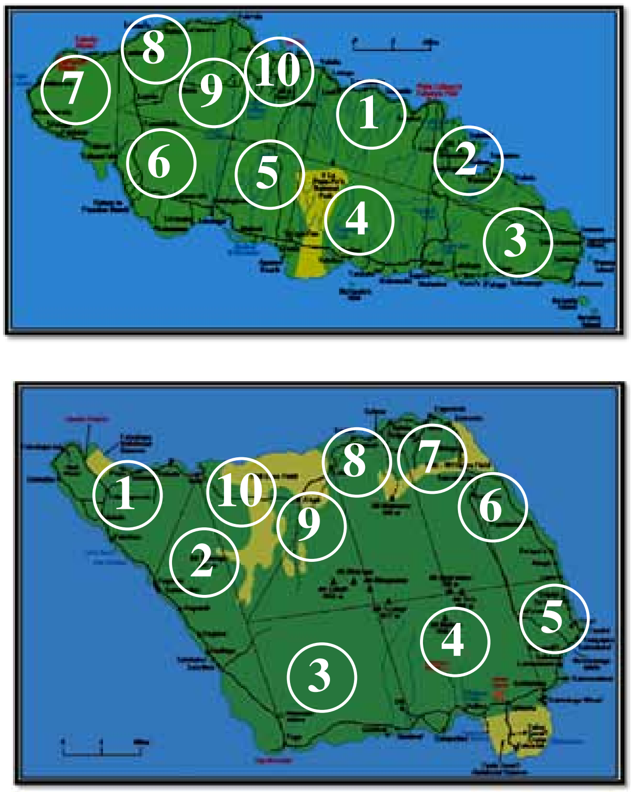
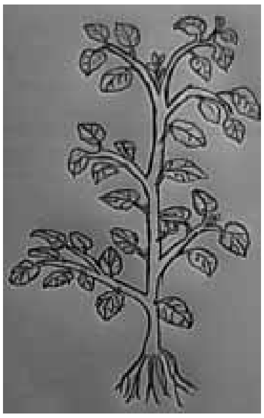
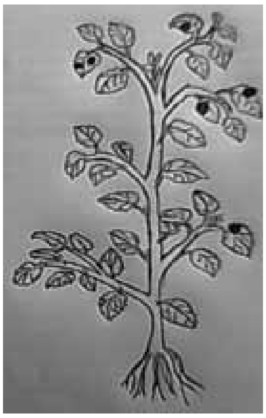
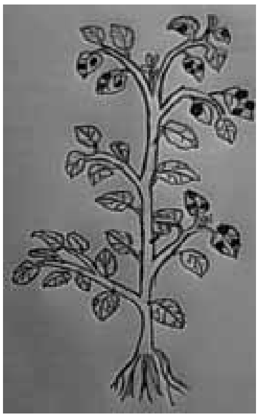
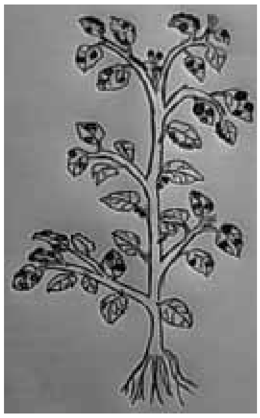


Figure 1. Map showing 10 survey zones in Upolu (above) and in Savaii (below).

A total of 100 households with possession of *H. rosa-sinensis* were randomly selected from each of the survey zones in both islands and physically examined for gall infestation, from July to September, 2009. A pictorial scale was created to assess the severity of gall incidences (Table 1).

Table 1. Pictorial scale for gall severity assessment.

Severity	None	Slight	Moderate	Severe
Pictorial				
Score	0	1	2	3

2.3 *Greenhouse experiment and Analysis.*
The greenhouse pot experiment was designed with one treatment factor (*H. rosa-sinensis*) and one design factor (CRD). There were 16 treatment levels (varieties) which were replicated five times; thus a total of 80 experimental units. The treatments were selected from commonly grown varieties in Samoa. Each unit (12 L pot) contained five cuttings.

A total of 25 cuttings of each treatment was randomly collected from gall free shrubs. Treatments were sterilized by a household detergent (Joy) at a ratio of 20ml to 20L of water. A liquid rooting hormone was applied to the cuttings prior to planting. Inoculation was done after six months of growing in greenhouse conditions. Gall infested branches of *H. rosa-sinensis* were introduced to every unit weekly and repeated four times to avoid bias. Gall recording was done weekly from 9/1/2010 – 8/5/2010. Recording started a week prior to first gall mite inoculation.

2.4 *Statistical analysis*
All recorded data was analyzed with the aid of the GENSTAT 3rd Edition software program.

3.0 RESULTS AND DISCUSSION

Taxonomic identification report from Dr. Danuta Knihinicki confirmed that Eriophyid gall mite, *Aceria hibisci* (Nalepa) (Figure 2a), was the causal agents for galls in *Hibiscus rosa-sinensis* L., in Samoa. There was also the presence of a male mite specimen belonging to the family Phytoseiidae from the Vaigaga sample. Phytoseiidae family is known to be predators of eriophyid (phytophagous) mites; hence presents the likelihood of a natural enemy. Another mite specimen belonging to the genus *Neopropilus* was identified; apparently was likely to be new to science. The role of this mysterious specimen in galls is yet to be determined. Such finding highlights the need for more research in this area of entomology in the Pacific Islands.

Results from the field survey confirmed that *H. rosa-sinensis* galls was not present in the Island of Savaii. However, galls were recorded from all 10 zones in Upolu (Figure 2b). Gall infestation was highly common with the red petal varieties. Analysis showed a variance of 260.8 and ó = 16.15; which implied that there was a significant difference between atleast two zones. The slight severity of galls in Upolu was recorded as the highest (Figure 3a). Calculations determined a variance of 242.68 and ó = 15.58. Thus, there was a significant difference between the Slight severity and all the other levels. Galls were irregular wart-like bumps on the buds and young leaves, fully developed leaves (Figure 3b), petioles, calyces, unopened flowers, and young stems. *Hibiscus schizopetalis* (mast) was the only alternate host plant identified in Samoa.

The results from the pot experiment implied that there was a significant difference between at least two of the 16 treatments (Table 2). This suggested

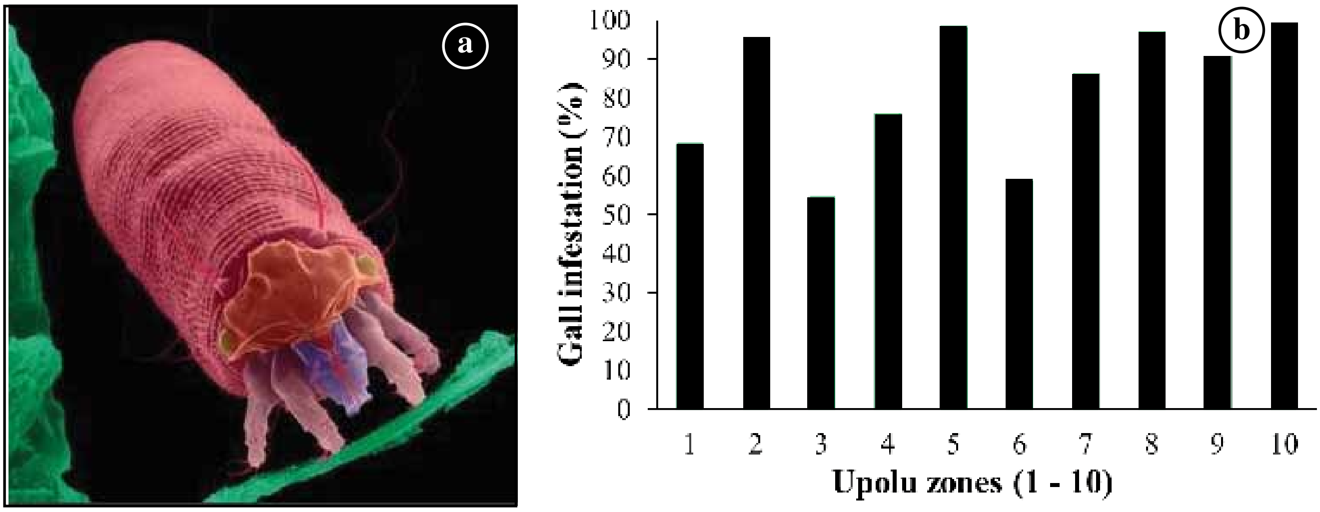


Figure 2 (a-b). (a) Adult of *Aceria hibisci* © Dennis Kunkel; (b) Gall infestation (%) in Upolu in 2009.

that varieties of *H. rosa-sinensis* have different levels of susceptibility to *A. hibisci.* Interestingly, local varieties of *H. rosa-sinensis* were more susceptable to galling than most of the exotic varities.

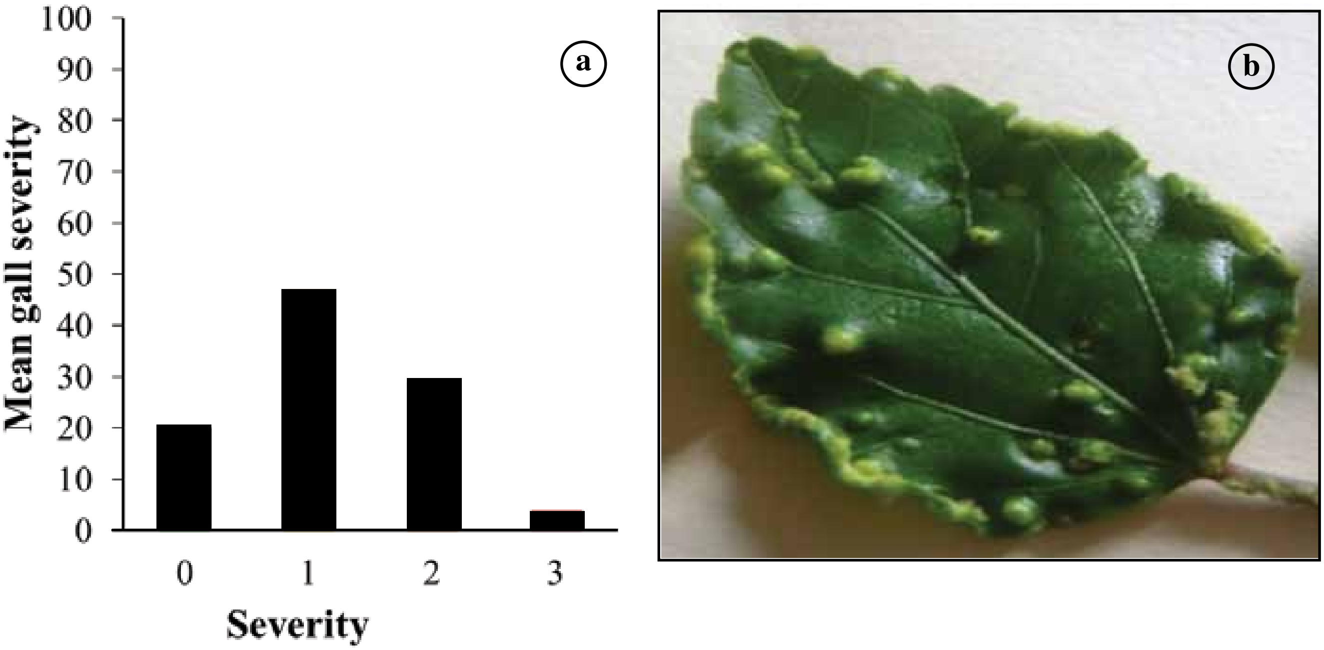


Figure 3 (a-b): (a) Mean gall severity on *H. rosa-sinensis* in Upolu, 2009; (b) Galls on fully developed *H. rosa-sinensis* leaf.

Table 2. One Way Analysis of Variance (no blocking) for Pot experiment (5% significance level).

Source of Variation	Deg. of Freedom	S.S.	M.S.	v.r.	F. pr.
Variety	15	3.48750	0.23250	2.48	0.006
Residual	64	6.00000	0.09375		
Total	79	9.48750			
Variate: Galling					

4.0 CONCLUSION

The galling of the *Hibiscus rosa-sinensis* L. in Samoa was caused by Eriophyid gall mite, *Aceria hibisci* (Nalepa). This particular galling does not occur in all Samoan Islands. The study highlights the importance of Biosecurity around the Pacific Islands. Galls were present in Upolu but not in Savaii may reflect on the effectiveness of biosecurity protocols at the domestic levels. However, there is free movement of planting material between Upolu and Savaii Islands, which is should be a concern in relation to future introduction and spread of the *A. hibisci.* This study agrees with Jeppson *et al.* (1975), Hara *et al.* (1996), De la Torre & Martinez (2004), Carson & Gough (2007), Welbourn *et al.* (2008) that *A. hibisci* is host specific, but may form galls on other *Hibiscus* species; besides *H. rosa-sinensis.* Moreover, there is a need for more research to better understand the gall formation process(s) and routine of the producer(s), in order to formulate effective biosecurity and or ecologically sustainable management strategies.

ACKNOWLEDGEMENTS

The principal author recognizes the inputs of Dr. Adama A. Ebenebe towards this research project design, and to the University of the South Pacific for the research facilities. Many thanks to Dr. Danuta Knihinicki, Department of Primary Industries, Plant Health Services, New South Wales, Australia, for the taxonomic facilities and mite species identification.

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RESEARCH PAPER

Rethinking Concepts of Human Health, Food and Nutrition Security in the Pacific Region in the Era of Climate Change with Focus on the Fiji Islands

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1.0 INTRODUCTION

1.1 *Global and Regional Climate change*

Worldwide, there is an increasing concern about the changing climate. Since its establishment in 1988, the Inter-governmental Panel on Climate Change (IPCC) has provided policy and program decision-makers with scientific information about climate change. The IPCC attributed greenhouse gases from human activity as being responsible for continuing global climate change with global temperature increasing between 1.8 and 4°C by 2100 (IPCC 2007). Increasing frequency and destructiveness of extreme weather events (EWE) such as tropical cyclones were documented (Emanuel 2005). After five IPCC reports and numerous occurrence of EWE globally, it has become clear that climate change impacts will have more damage with increasing global temperature. Human-induced (anthropogenic) warming may lead to some abrupt and irreversible impacts which are dependent on the rate and magnitude of the climate change. Regional variations of these consequences are evident (Patz and Kovats 2002). Some countries may benefit in the short or medium term, but economic challenges to many developing nations including Pacific island countries and territories (PICTs) are anticipated. In these reports, it is certain that the most vulnerable and poorest developing countries will experience significant consequences if mitigation and adaptation strategies are not subscribed to. At this stage, though many developing countries have less contribution in the anthropogenic cause of climate change, their on-going transition to a consumption economy will also contribute in accelerating global environmental change. Therefore, both developing and developed nations have a common obligation to support each other in efforts to mitigate and adapt to climate change (IPCC 2012). Many countries and international agencies are mainstreaming climate change in their development agenda; however, more needs to be done in implementing policies. The future of human health and food nutrition security depends on everyone's efforts and action to strive for global environmentally-sustainable development. The IPCC 4th Assessment Report indicated that the climate of the PICTs has changed in the last several decades. Since 1910, ocean and land temperatures have increased 0.6-1°C (SPC Land Resources Division 2010). Parts of the region such as the Southwest Pacific have become drier while the Central Pacific have experienced increasing rainfall (Manton 2001). Change in the climatic trends including increasing sea-level rise are also projected to continue in the next decades. Annual and inter-decadal variability in climatic variables temperature and rainfall are felt due to the ENSO (El Nino/La Nina Southern Oscillation) which influences prevailing regional climate. All these are anticipated to impact on health, food and nutrition security.

1.2 *Climate change, health, food and nutrition security and its multi-sectoral links*

In the last decade, the connections between climate change and human health have been widely accepted (Berry *et al*. 2010; Confalonieri *et al*. 2007; Costello *et al.* & UCL Institute for Global Health and Lancet Commission 2009; McMichael 2003). The climate-health pathway indicates that the consequences of climate change are not only confined to the direct environmental and economic impacts. Indirect pathways and inter-related mechanisms affect health and nutrition through the intermediate factors that involve agriculture, infrastructure and transport, sanitation and water, health services including disaster planning and management (Bowen *et al.* 2013). Unfortunately, many of the health effects will be unevenly distributed. People in developing countries and the marginalized sector in a developed society may experience severe outcomes (Friel and Baker, 2009; Friel *et al*. 2008; Wahlqvist *et al.* 2009). Many of the developing countries have fragile or transitioning economies with insufficient financial capability, poor governance, lack of infrastructure, and poor living conditions that add to the high level of disease risk burden which will be exacerbated by a changing climate (McMichael *et al.* 2004; McMichael *et al*. 2006; Patz *et al*. 2005; Patz and Kovats 2002).

1.3 *Aims of this paper*

The aims of this paper is to highlight the importance of how climate change is affecting health, food and nutrition security with Fiji and to propose a conceptual framework for better understanding on how climate change may affect health and food and nutrition security. A socio-ecological perspective is used to address these issues. Coordinated efforts from multiple sectors in society including agriculture, finance, social welfare and others are vital to food security and health attainment and are relevant to health-related adaptation initiatives to climate change. The following key questions are addressed: a) Is climate change happening in Fiji? b) Is climate change affecting health, food and nutrition security in Fiji? c) What are the impacts of climate change in Fiji relevant to health, food and nutrition security? and d) How should we use a socio-ecological perspective to address issues of health and food and nutrition security in the era of climate change?

2.0 APPROACH AND METHODS

2.1 *Adapted Socio-ecological Model of Health*

Here, the theoretical underpinnings in approaching the linkages to propose adaptation strategies for climate change, health and food and nutrition security is based on a socio-ecological theory (McLeroy *et al*. 1988; Stokols 1996), ecological systems theory/human ecology theory (Bronfenbrenner 1979) and social cognitive theory (Bandura 1986), among others. In climate change studies, socio-ecological models extending to health utilizes an integrated systems approach. It has evolved to include conceptual frameworks from multiple disciplines to explain the complexity of how climate change will affect human health and food and nutrition security (Llamas-Clark 2011). This conceptual development is based on the underlying principle that multiple factors at different levels influence nutrition and therefore, health and well-being.

As a public health approach, the socio-ecological model has been widely used for health promotion strategies. It recognizes the several levels in understanding the links between individual and the physical and social environment (McLeroy *et al*. 1988). Individuals are integral to this concept. However, interpersonal relationships, community and societal dynamics and institutional structures are equally important. Future interventions aimed at achieving satisfactory health and nutrition outcomes require a combination of individual, interpersonal (household), community, and public policy initiatives. (Fitzgerald 2009; Winch 2012). Climate Change and Health Pathway (Fig. 1) provides the conceptual framework to illustrate several direct and indirect pathways leading to the climate-health relationship including food and nutrition security outcomes (McMichael and Haines 1997).

2.0 METHODS

A review and synthesis of available Pacific research studies and literature in the last 20 years on climate change, food security, health and malnutrition (undernutrition) focusing on Fiji was undertaken. Google scholar, Web of Science and Pubmed were searched using key words climate change, health, food security and nutrition security and Fiji. Additional search was done using references from available literature. Grey literature was sourced from the local libraries.

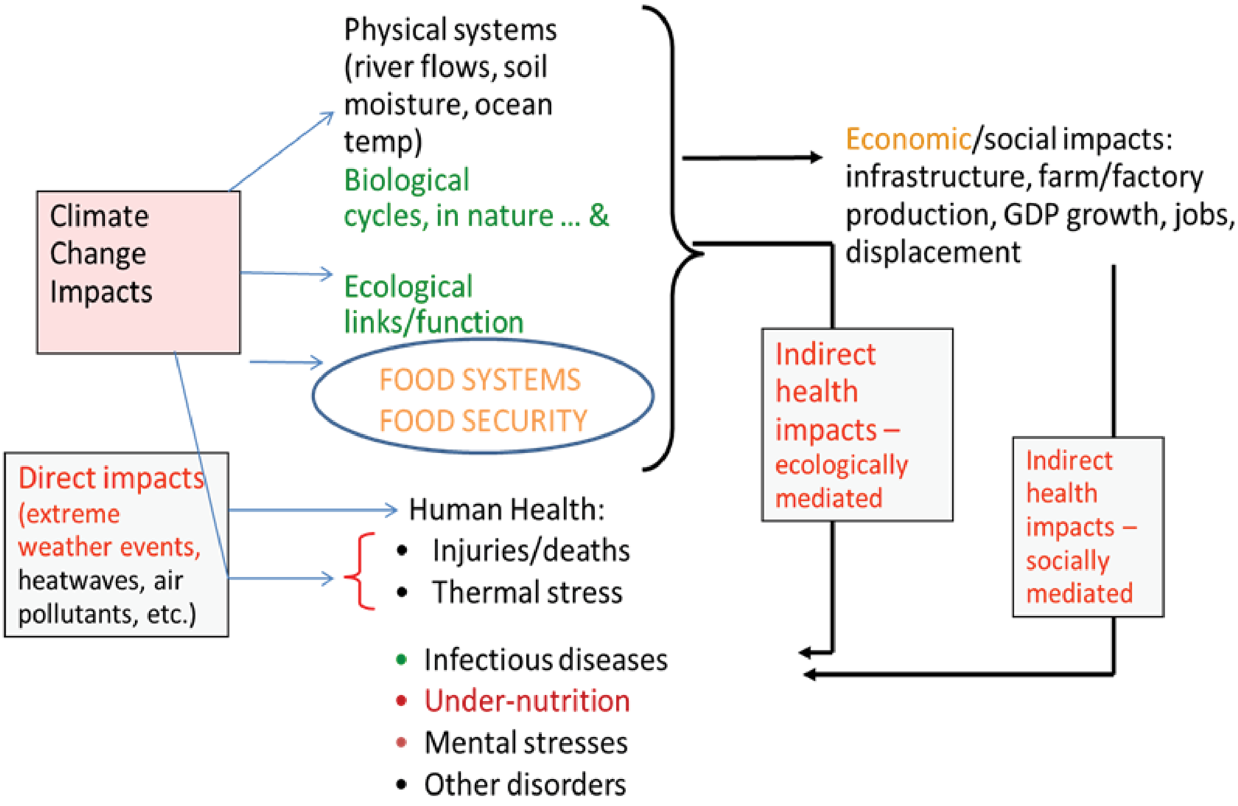

Figure 1. Climate Change and Health Pathways (McMichael, 2010)

A public health perspective was used to understand the issues of health and food and nutrition security against the background of climate change. A guide to the direct and indirect health effects of climate change (Clark 2014) was used in selecting studies to be included. Based on the literature, findings of the first three key questions are discussed. Thereafter, the proposed Comprehensive Conceptual framework is explained. With climate change predicted to increase EWEs and disasters in future, this framework could be used to develop possible strategies to address health and food and nutrition security.

3.0 RESULTS AND DISCUSSION

In the last two decades, studies on climate change and health has been slowly increasing due to research awareness and support. Many of these studies in recent years have been largely concentrated on climate adaptation strategies undertaken by the collaboration of technical, development and academic organizations. This study concurs with other research that there is still a need to fill gaps in knowledge, research and practice in Fiji and the rest of the PICTs in relation to climate change and its impact on health and food and nutrition security.

3.1 *Is climate change happening in Fiji?*

Climate and Climate Change in Fiji. Fiji has a tropical climate with two distinct seasons, wet and dry, The warm wet season occurs between November and April, and the dry and cooler season from May to October. Seasonal temperature changes is minimal and dependent on the Pacific Ocean's temperature. The annual average temperature is between 20-27°C. The average night time temperature in the central parts and the coast is 15°C and 18°C respectively.

The maximum high temperature in the country is 32°C. Fiji's average rainfall is around 1,800 mm per year. It has a variable rainfall pattern that is dependent on the several factors such as the South Pacific Convergence Zone, mountain elevations, and east or south-east trade winds including the regional climate influence of ENSO (Bell *et al.* 2011; SPC and CSIRO 2011).

Under the low and high emissions scenarios for 2,035 and 2,100, air temperature and rainfall based on long-term averages are projected to increase. Surrounding ocean waters sea surface temperature, sea level and acidification are also anticipated to rise (Bell *et al.* 2011).

Tropical cyclones (TC) and consequent floods A tropical cyclone is a rotating windstorm developing over several days over waters warmer than 26.5°C that also has unpredictable paths (SOPAC, Sept 2006). Several factors such as sea surface temperature, wind speeds, humidity and atmospheric and trophospheric condition determine the formation and frequency of TC (Krishna, 1984; Walsh & Pittock, 1998). In Fiji, TCs occur when the Southern Oscillation Index has negative values and flooding happens in all TC during El Nino (Kostaschuk *et al.* 2001).

The 2013/14 TC seasonal forecast indicated that overall, there would be above average TC activity, with 1 to 2 TC affecting some parts of Fiji, with 1 expected to reach Category three (3) or above. Also, active cloud and rain bands associated with TCs nearby Fiji were predicted to bring heavy rain and stormy conditions with anticipated flooding and storm surge in low-lying coastal areas (Fiji Meteorological Services 2013).

Floods Major floods are associated with TCs and cause negative public health effects (Malilay, 1997). An approaching TC brings heavy rainfall with increasing intensity causing runoff from saturated catchment areas resulting in extensive floods. Low magnitude floods also occur due to seasonal weather events with high intensity rainfall. Annually, 1-2 TCs with high intensity rainfall affect Fiji. The scale of the flood depends on the distance, intensity, movement and speed of the TC system. Flash floods also occur infrequently including storm surges along coastal areas. When levees and seawalls are breached, flooding occurs. Documented TC-related floods have occurred in the Rewa River, one of the most important water systems in Fiji (Kostaschuk *et al.* 2001; Raj 2004). TCs and floods in the last decade have caused heavy losses to agriculture that have had economic, food security and health impacts. As an example, the 2003 Hurricane Ami which approached rapidly brought torrential rainfalls and record-breaking floods (Terry 2005).

3.2 *What are the impacts of climate change in Fiji relevant to health, food and nutrition security?*

Health Impacts of Climate Change in PICTs and Fiji Like many countries in the Pacific, Fiji needs to address future health and food and nutrition security concerns. Climate change will be one of the ecological factors that will add to the future challenges of a country undergoing socio-economic and demographic transition. The yearly monsoon season between November and April brings public health risks of injury, death and diseases. Fiji is no exception to stories of disaster and devastation due to TCs. The cyclical occurrence of ENSO has significant effects on public health with impacts of natural disaster increasing during the El Nino years (Kovats *et al.* 2003). Likewise, vector-borne diseases such as dengue fever in the South Pacific were linked to ENSO (Hales *et al.* 1996). Diarrheal diseases have positive association with increasing average annual temperature in El Nino years in 18 PICTs. More specifically, in the years 1978–1998, it was demonstrated that there were positive associations between increasing infant diarrhea reports in Fiji and increasing temperature and extremes of rainfall (Singh *et al*. 2001). Climate-sensitive health risks in the PICTs are being targeted by the WHO. In Fiji, dengue fever, typhoid fever, leptospirosis, diarrhoeal disease remain priorities. The recent dengue outbreak, which is due to the type 3 strain that has never been seen previously, claimed 11 confirmed deaths and more than 15,000 cases and was linked to climate change (Koroitanoa 2014).

Economic Impact of Tropical Cyclones to Fiji Tropical cyclones and its consequent flooding bring immediate damage to agriculture, infrastructure and the economy, as well as bringing demographic, land use and socio-economic changes and environmental stress. For example, TC Bebe (1972) affected the Yasawa Islands, Viti Levu and Kadavu causing 19 deaths with a reported damage bill estimated to have been more than F$20 million. In 1993, TC Kina passed the main islands of Viti Levu and Vanua Levu, causing 23 deaths and an estimated F$170 million worth of damage, making it one of the deadliest and most expensive hurricanes in Fiji's recent history. TC Cyclone Ami left fourteen people dead and an estimated cost of damage of FJ$104.4 million. TC Evan in 2012 caused $75.29 million worth of damages (Kuleshov *et al*., 2013).

3.3 *Is climate change affecting health, food and nutrition security in Fiji?*

Climate change impact on food and nutrition security in Fiji. Traditionally, PICTs rely on subsistence agriculture and fishing practices. People eat local staples such as roots and tubers, bananas and breadfruits and rely on fish and seafood as source of protein. Since the 1970's, imported foods complemented traditional food enhancing food security. However, with this dietary consumption change, the health and nutritional outcomes of Pacific populations is at risk. Based on the 2004 National Nutrition Survey, the growth pattern of children less than five years of age showed both over and under the reference standards. Overall, 14.5% and 12.5% of children less than 18 years were overweight and underweight respectively. The prevalence of anemia was documented to be high (33.5% in rural and 31% in urban areas). Only 40% of infants were exclusively breastfed. Vitamins and minerals were deficient in the diet of most Fijians (National Food and Nutrition Centre (NFNC) 2004).

Fiji has supported initiatives to "ensure that all their people, at all times, have physical, social and economic access to sufficient, safe and nutritious food" in conjunction with the Pacific approach to fulfill the "Healthy Islands" objectives. It has also supported land acquisition for food security for a neighboring country, Kiribati, that has been threatened by rising sea level rise attributed to climate change (Marau 2013). Fiji's national government agenda on agriculture in recent years has been targeting commercialization while maintaining subsistence farming, fishing and livestock as the backbone of household's food security, particularly in the rural areas.

The main produce includes palm oil, coconut, sugarcane, cocoa and coffee plantations, and beef cattle. Modern methods of farming are still underdeveloped and many challenges due to availability and quality of seeds and crop planting material, post-harvest losses, poor animal health and high cost of purchased feed, pest control and management, shortage of human labour, expensive mechanized equipment and limited and underdeveloped domestic and export marketing.

Apart from food production and supply issues, food security is impacted by a several complex factors including and most importantly the changing climate and its weather events and consequent natural hazards and disasters. Some studies have shown that with climate change, TCs will become more intense with larger peak wind speeds and heavier rainfall (FAO 2010). These projections are likely to destabilize mostly rain-fed agriculture. Crops are more likely to be frequently damaged from the increasing winds and heavier rainfall. Coastal agricultural lands will also be increasingly impacted by fresh water salinization due to storm surges thereby decreasing overall crop yields. The life cycle of insects and plant pests could potentially devastate food sources. This was documented by the occurrence of taro leaf blight in some PICTs including Fiji which threatened the availability of traditional staple food (Singh *et al*. 2012). Regional and national germplasm collection was developed as a climate change adaptation (McGregor *et al*. 2012)

In terms of ocean fisheries and aquaculture, water productivity is variable and depends on the nutrients of the ocean. Fisheries will likewise be potentially vulnerable due to fish stocks moving away from the Pacific exclusive economic zones (EEZ). Some types of fish such as big eye and skipjack tuna are expected to increase but overall, the changed ocean environment can bring less catch affecting locals dependent on seafood for their protein.

Climate change impact on health in Fiji Environmental change and natural calamities can trigger economic shocks that can also impact household food security. Food production and supply is heavily dependent on the prevailing climatic variables and food prices can increase when there is lack of supply. Increases in fuel prices also determine food price volatility. These external factors can impinge on a household's capacity to access food of different varieties. Availability and accessibility of particular types of food determine the dietary patterns and nutritional consumption of people that keep them healthy and well.

The effect of climate and weather has the ability to change the state of nutrition and food security of the population, which has important implications for the well-being of individuals, households and societies. Several PICTs have a double burden of high rates of under and overweight and obesity (Grieve *et al*. 2013). One of the direct consequences of food insecurity is hunger and malnutrition.

From the 1950's, several national nutrition surveys have been conducted in Fiji. Protein-energy malnutrition, anemia, micronutrient deficiency and recently overweight and obesity have challenged the state of nutrition of Fiji. The state of nutrition is ultimately linked to the physical and social environment. Future health and nutritional interventions will need to take into account the impact of a changing climate.

Climate change has brought a rising incidence of climate-sensitive diseases and health risks such as air, water and vector-borne diseases such as malaria (Githeko 2009; Rivera, 2009), dengue fever (Colón-González *et al.* 2013), and ciguatera poisoning (Llewellyn 2010). Many climate change support activities are provided in the PICTs from numerous organizations (SPC 2012). The economic and environmental sectors are given priority but health investments seem to be scarce in comparison and need to be strengthened. Climate change and its consequences is a major public health risk of this century (Costello *et al.* 2009).

3.4 *How should we use a socio-ecological perspective to address issues of health and food and nutrition security in the era of climate change?*

Figure 2 shows the schematic diagram that explains the interrelationships among the factors that are considered in this research: EWEs, food security and population health specifically in relation to the status of nutrition and health of children at the household level. It also indicates that EWEs lead to direct and indirect impacts on the socio-economic conditions of the community and individual households (Clark 2014). This framework has been used in the Philippines and is also applicable in Fiji.

More frequent and intense EWEs occurrence such as typhoons and floods are consequences of climate change. Some factors can influence the impacts of EWEs. The physical characteristics of a locality such as watershed, existing land use, vegetation and forest cover, and river and lake system's conditions influence the environment-related problems which magnify the magnitude of the impacts of EWEs.

In Figure 2, Boxes A and B indicate that Fiji's climate and weather indicators showed some changes such as increasing temperature, while there appears to be no significant trends in rainfall and cyclone occurrence. The frequency of cyclones has not changed but there are suggestions of increased cyclone intensity was noted. EWEs can lead to increasing incidence of floods that impact local conditions.

Box C shows that EWEs have direct and indirect impacts on food security. EWEs can suddenly decrease food production (FP) areas which can threaten and abruptly decrease food availability/ supply. EWEs decrease the amount of crop production for families which can reduce the amount of food available for consumption. Apart from decrease in food supply, food access due to loss or lack of income leads to a decrease in dietary intake. Coping strategies in food preferences and allocation within household members are adopted.

In Box D, changes in national climate and local weather conditions can have both direct and indirect health effects at the community and households. The direct effects are injuries, deaths, initial hunger, and infectious diseases and mental stress. These short-term direct effects can compromise the health, socio-economic and food security of the household particularly if the head of household is affected. The indirect long-term health effects are changing incidence of illnesses and undernutrition. Again, these health effects are also influenced by both the socio-economic and nutritional status of the household.

In Box E, environment-related problems that cause flooding can magnify the impacts of the EWEs. It can also have socio-economic direct and indirect impacts to the community and households. In the community, EWEs can destroy infrastructure such as housing, hospitals, and communication facilities. It can also disrupt water supply and social services that are essential in maintaining health. Households during EWEs can experience a decrease in income and inability to access health and social services. EWEs also have an additional impact depending on household credit and insurance availability.

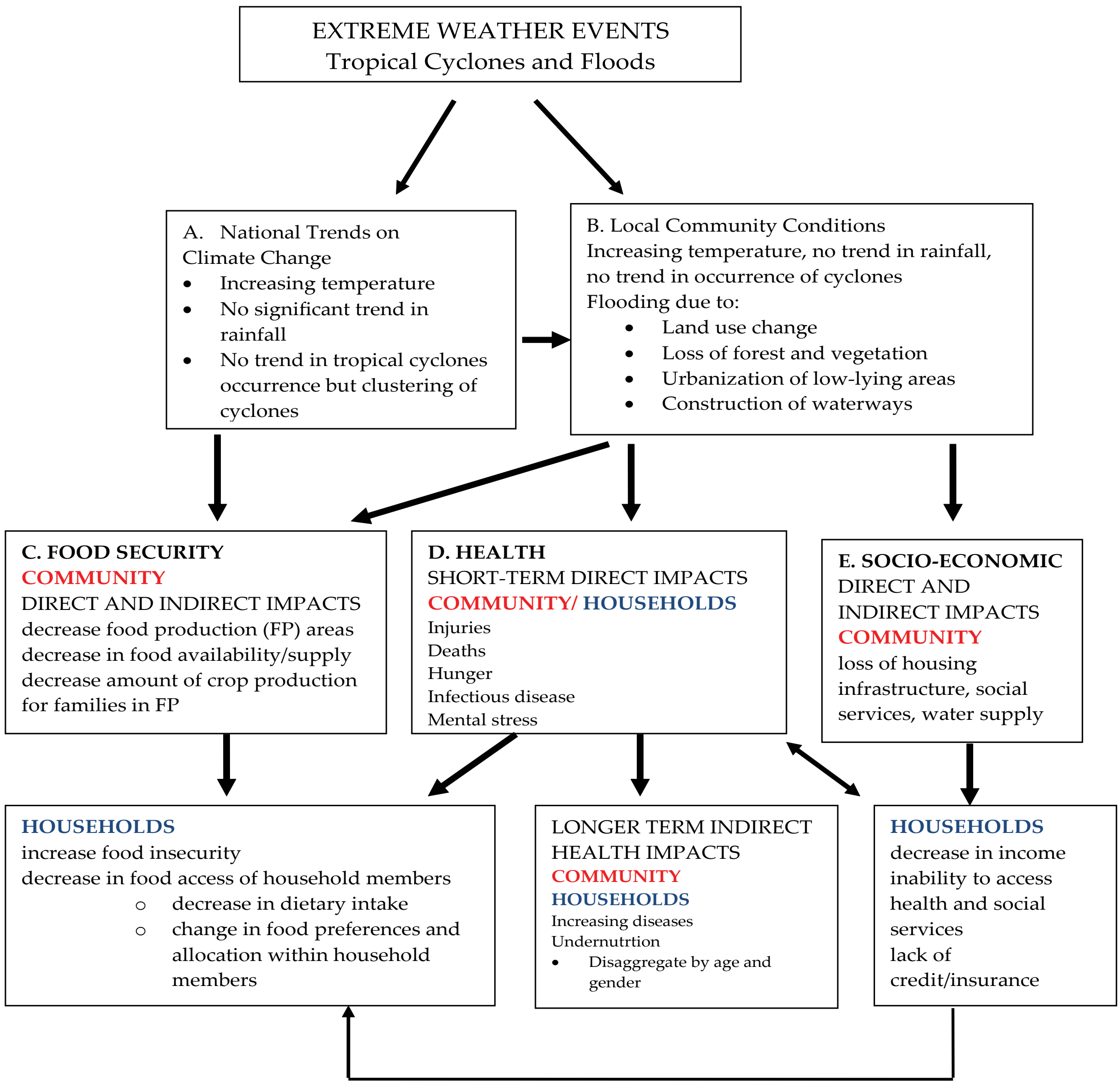

Figure 2. Extreme Weather Events, Food Security and Population Health Operational Framework
Source: Clark (2014) Chapter III unpublished Thesis

4.0 CONCLUSION

This paper presented the evidence that climate change is happening in Fiji. The projection of increasing EWEs such as cyclones and floods present a risk to people as they transition from a subsistence to consumerist economy. This economic change including the global environmental and climate change impact health and nutrition outcomes. To be able to address the challenges of climate change including increasing EWEs and natural disaster occurrence in the context of Pacific Island countries such as Fiji in achieving health and food and nutrition security, a socio-ecological conceptual framework was deemed necessary. There are many possibilities in research, policies and programs. Highlighting health and supporting the health sector is critical to the climate change initiatives. Reorienting all other sectors to collaboratively work and look at good health and nutrition as the end goal for all efforts to address climate change could provide a meaningful incentive to achieve a sustainable environment for healthy living. In future, this will be proof that the socio-ecological model has provided a holistic framework that can be utilised and adapted to achieve beneficial outcomes when addressing climate change.

ACKNOWLEDGEMENTS

I sincerely thank the SPC Suva Library, Fiji Food and Nutrition Library for access to their library resources. I also thank Mr. Brenton M. Clark for his time in engaging in discussions and providing suggestions and Dr. Ravindra C. Joshi for reviewing the manuscript.

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RESEARCH PAPER

Abundance of non-native plant species in taro (*Colocasia esculenta*) farms on selected sites in Taveuni Island, Fiji

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ABSTRACT

Weed species composition, biology, density and distribution in crop production systems in Fiji are poorly documented. Such information is vital towards their management. Survey of weeds on four taro fields in Taveuni Island was conducted to determine their composition, density and frequency. Experimental surveys were done on first, third and six months after planting of taro using a 1m x 1m quadrant on the same 12 spots on each site. A total of 46 weed species belonging to 20 plant families were recorded on taro of which all except one was non-native to Fiji. This study revealed that bristly foxtail grass (*Setaria barbata* Kunth) was the most dominant weed species in taro production in Taveuni followed by goatweed (*Ageratum conyzoides* L.), tarweed (*Cuphea carthaginensis* (Jacq.) MacBr.), thickhead (*Crassocephalum crepidioides* (Benth.) S.M.) and wedelia (*Sphagneticola trilobata* (L.) Pruski). This paper presents the first record of weed species composition and density on taro cultivation in Taveuni.

Key words: *Colocasia esculenta,* weeds, Taveuni, non-native plants.

1.0 INTRODUCTION

Weeds are plant pests growing where they are not wanted. They are considered the most underestimated pest in the tropics but their impacts to crop production is greater than those from arthropods or pathogens (Akobundu 1987). Attributed to various biotic and abiotic factors, crop yield losses caused by weeds vary from crop to crop and from region to region (Tamado and Milberg 2000). Yield loss caused by weeds was estimated to be ca. 10% in the less developed countries and ca. 25% in the least developed countries (Akobundu 1987).

The relative importance of common weed species in taro cropping systems is not well documented in Fiji. The existence of weeds in cropping systems is the outcome of ecological reactions to previous management practices, soil characteristics of the site, climatic conditions and competitive ability of weed species (Salonen 1993; Andersson and Milberg 1998; Milberg *et al.* 2000). The methods of weed control employed such as chemical, cultural, mechanical and biological could strongly influence types and population of weeds in an area (Chancellor 1985). Therefore, knowledge of the dynamics of a weed community structure is an integral component of weed management in any crop production system (Kropff and Spitters 1991). Such understanding is vital in designing strategies for both weed management and research (Kropff and Spitters 1991; Robinson *et al.* 2007).

The production of agricultural crops in Fiji is threatened by the invasion of weeds. The presence of weeds among crops leads to increased production costs and a reduction in crop productivity (Auld *et al.* 1987), and at some stage their impacts may be greater than those caused by other plant pests (Oerke 2006). The amount of crop yield losses due to weeds in Fiji is relatively unknown. However, commercial root crop farmers rely more on herbicides to control weeds than other methods of weed control (Macanawai *et al.* 2011). A weed management trial on taro at Koronivia Research Station, Fiji in the late 1970s, demonstrated that the taro yield from unweeded plots was reduced by as much as 85% (Sivan 1981). Keeping the taro crop weed free from planting to harvesting required seven hand-weeding operations (Sivan 1981), while herbicide control may require 2-3 times of application (*personal observation*). According to Macanawai *et al.* (2011), application of herbicide remains the main method for controlling weeds in taro farms in Lomaivuna, Naitasiri Province, Fiji as it is economical and less labour intensive than manual weeding. Similar practice is occurring in taro production areas in Taveuni (Waisea Railumu, Agriculture Extension Office-Taveuni, *pers. comm.* 27 May 2013). Controlling weeds in cropping areas using other methods of control such as inter-row cultivation by machines or animals, burning and biological control has also been reported in Fiji (Macanawai 2011).

Taveuni Island is currently the major producer of the main export taro (*Colocasia esculenta* L. Schott) variety 'Tausala ni Samoa' in Fiji (Timoci Bogidua EP&S Ministry of Agriculture, *pers. comm.* 20/09/2012). There are ca. 3,600 taro farmers in Taveuni who cultivated ca. 0.5 – 2.0 ha per crop annually (Timoci Bogidua EP&S Ministry of Agriculture, *pers. comm.* 20/09/2012). The island produces an annual average of ca. 4,800 tonnes of taro for export from 2002–2005 which generated ca. FJD $5 million into the local economy annually (Timoci Bogidua EP&S Ministry of Agriculture, *pers. comm.* 20/09/2012). In recent years, taro production in Taveuni has increased to about 7,000 – 8,000 tonnes for the export markets (The Fiji Times, Saturday 22/09/2012 p.14).

Studies on the distribution and abundance of weeds on crop production system in Fiji are relatively unknown. Thus weed species diversity, their distribution patterns, frequency, density and abundance within taro farms in Taveuni Island, were conducted using experimental surveys on four randomly selected sites. In addition, weed species that are a potential threat to taro production were identified. The results obtained from this particular study will form the baseline information for future weed management research in Fiji.

2.0 MATERIALS AND METHODS

2.1 *Study site*

Weed surveys were conducted on four Soil Health (Australia Center for International Agricultural Research-funded project) 'Tausala ni Samoa' taro variety field trials in Taveuni from October 2012 to March 2013. The study sites were located in Matei (16°41.8'S, 179°52.7'W), Delaivuna

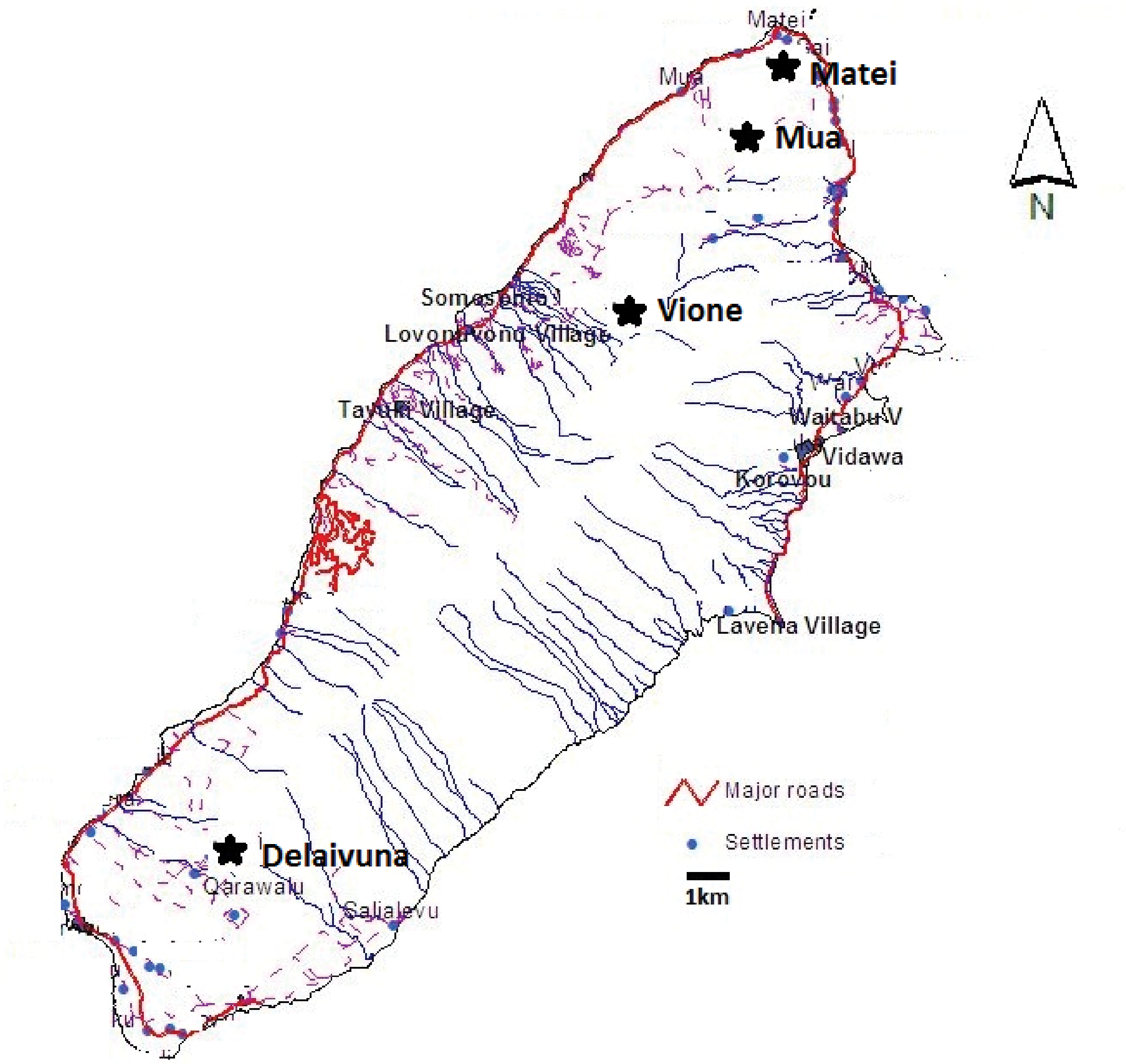

Figure 1. Map of Taveuni showing the four study sites (Map source: GPS Unit, LRPD, 2012)

(16°57.9'S, 179°56.8'E), Mua (16°43.01'S, 179°54.3'W) and Vione (16°46.2'S, 179°56.79'W) (Fig. 1). There were 20 plots with 64 taro plants, spaced 1m x 1m apart, per plot on each site. Weeds were sampled on 12 plots, i.e. plots 1-4, 9-12 and 17-20 (Fig. 2). The taro study sites Matei, Delaivuna, Mua and Vione were planted on 11th to 14th September 2012, respectively. Three surveys were conducted during the growth stages of taro at one, three and six months after planting on each of the four study sites.

1	8	9	13	20
2	7	10	14	19
3	6	11	15	18
4	5	12	16	17

Figure 2. Taro trial layout on Matei, Delaivuna, Mua and Vione study sites. The shaded regions were the sampled plots at one, three and six months after planting.

$$\text{RLF}(\%) = \frac{\text{Absolute frequency value for a given species}}{\text{Total absolute frequency for all species}} \text{x } 100 \qquad (1)$$

$$\text{RLD}(\%) = \frac{\text{Absolute density value for a given species}}{\text{Total absolute density for all species}} \text{x } 100 \qquad (2)$$

$$\text{IPV} = \text{RLF} + \text{RLD} \qquad (3)$$

The frequency (F) value indicates the percentage of taro fields infested by a particular weed species and is considered to be an estimate of the extent of infestation in a region (Mehdi *et al.* 2008).

$$F_x = \frac{\Sigma Hr}{n} \text{ x } 100,$$

Where Fx is the frequency value for each weed species x, Hr is the presence of species x in field r, and n is the total number of quadrats taken in field r.

The density of the species is a value that indicates the number of individuals of a species per m^2. The mean field density was calculated and this value indicates the magnitude of the infestation in all the surveyed sites (Mehdi *et al.* 2008).

3.0 RESULTS

The survey of each of the four taro fields on three separate occasions during the growing stages of taro in Taveuni revealed a total of 46 weed species belonging to 20 plant families that were associated with taro cropping. The analysis of data showed that majority of weed flora species identified are from the Poaceae family (nine species), followed by Asteraceae and Euphorbiceae (five species each), Fabaceae (four species), Cyperaceae and Solanaceae (three species each) and Acanthaceae, Cucurbitaceae and Malvaceae (two species each). The rest of the 11 families (Araceae, Convolvulaceae, Dioscoreaceae, Lamiaceae, Lythraceae, Myrtaceae, Passifloraceae, Polygalaceae, Rubiaceae, Scrophulariaceae and Verbenaceae) observed to have only a single plant species in the four study sites. Out of the 46 weed species, all were introduced except (*Macaranga marikoensis* A. C. Sm.) (rote), a native tree species.

At one month after planting, the five species that were present in all the four sites were thickhead (*Crassocephalum crepidioides* (Benth.) S.M.), morning glory (*Ipomoea indica* (Burm.f.) Merr.), mile-a-minute (*Mikania micrantha* Kunth), mucuna (*Mucuna pruriens* (Lour.) D. Chev.) and wild cape gooseberry (*Physalis angulata* L.) (Table 1). However in Mua, bristly foxtail grass (*Setaria barbata* Kunth.) was the most dominant plant species with an IPV of 76.0% and RLD and RLF values of 64.2% and 11.8%, respectively. Similarly in Matei, *S. barbata* was the most dominant plant species with an IPV of 85.4% and RLD and RLF values of 68.3% and 17.1% respectively (Table 1). In Vione, goatweed (*Ageratum conyzoides* L.) was the most dominant with an IPV of 63.2%, RLD value of 51.3% and RLF value of 11.9% (Table 1). In Delaivuna, wedelia (*Sphagneticola trilobata*) was the most dominant with an IPV of 71.3%, RLD and RLF values of 57.0% and 14.3% respectively, at one month after planting (Table 1).

The data analysis at three months after planting showed that the only two species that were present in all the four sites were *M. micrantha* and *S. barbata* (Table 2). Similar to one month after planting, *S. barbata* was the most dominant plant species in Mua and Matei. In Mua, *S. barbata* attained an IPV of 61.6%, RLD and RLF values of 42.4 and 19.2%, respectively. In Matei, *S. barbata* attained an IPV of 68.8%, RLD and RLF values of 49.5% and 19.3%, respectively (Table 2).

In Vione, *A. conyzoides* was again the most dominant with an increased IPV of 100.9% and RLD of 88.5% and RLF values of 12.4%. However, in Delaivuna, tarweed (*Cuphea carthaginensis*) was the most dominant with an IPV of 58% and RLD and RLF values of 35.4% and 22.6% respectively, at three months after planting (Table 2). At six months after planting, the analysis of data

Table 1. Data showing the relative density (RLD), relative frequency (RLF) and importance value (IPV) of weeds species in a taro crop in Mua, Matei, Vione and Delaivuna, Taveuni Island at one month after planting. The bolded data represent the species that were present in all the four sites and the most dominant in each site.

		RLD (%)				RLF (%)				IPV (%)			
Weed species	**Family**	**Mua**	**Matei**	**Vione**	**D/vuna**	**Mua**	**Matei**	**Vione**	**D/vuna**	**Mua**	**Matei**	**Vione**	**D/vuna**
***Ageratum conyzoides* L.**	**Asteraceae**	–	**0.05**	**51.27**	**7.78**	–	**1.43**	**11.89**	**12.79**	–	**1.48**	**63.16**	**20.57**
Amorphophallus campanulatus (Roxb.) ex. De.	Araceae	–	0.11	–	–	–	1.43	–	–	–	1.53	–	–
Centrosema molle Mart. ex Benth.	Fabaceae	1.15	0.37	0.12	–	6.78	8.57	2.02	–	7.93	8.94	2.14	–
Coccinia grandis (L.) Voigt	Cucurbitaceae	–	0.85	–	–	–	11.43	–	–	–	12.28	–	–
***Crassocephalum crepidioides* (Benth.) S.M.**	**Asteraceae**	**5.38**	**1.38**	**2.73**	**0.05**	**16.94**	**8.57**	**9.87**	**1.53**	**22.32**	**9.95**	**12.60**	**1.57**
Cuphea carthaginensis (Jacq.) MacBr.	Lythraceae	–	–	29.95	20.50	–	–	10.94	19.08	–	–	40.89	39.58
Cyperus rotundus L.	Cyperaceae	–	–	1.61	–	–	–	3.92	–	–	–	5.54	–
Digitaria setigera Roth ex Roem. & Schult.	Poaceae	10.61	–	0.02	–	5.08	–	–	–	15.69	–	–	–
Dioscoria bulbifera L.	Dioscoreaceae	–	0.08	0.15	–	–	4.29	2.97	–	–	4.37	3.12	–
Echinochloa colona (L.) Link	Poaceae	–	0.08	–	–	–	1.43	–	–	–	1.51	–	–
Eleuranthera ruderalis (Sw.) Sch. Bip.	Asteraceae	–	26.54	0.33	–	–	15.71	3.92	–	–	42.26	4.25	–
Eleusine indica (L.) Gaertn.	Poaceae	–	–	5.10	1.71	–	–	7.97	6.30	–	–	13.07	8.01
Euphobia hirta L.	Euphorbiaceae	–	–	0.02	–	–	–	–	–	–	–	–	–
Homalanthus nutans(G.Forst.) Guill.	Euphorbiaceae	–	–	–	0.21	–	–	–	1.53	–	–	–	1.73
Hyptis pectinata (L.) Poit.	Lamiaceae	0.69	–	0.43	–	8.47	–	4.99	–	9.16	–	5.42	–
***Ipomoea indica* (Burm.f.) Merr.**	**Convolvulaceae**	**0.23**	**0.03**	**0.13**	**0.09**	**5.08**	**1.43**	**2.97**	**1.53**	**5.31**	**1.46**	**3.10**	**1.62**
Kyllinga polyphylla Willd. ex Kunth.	Cyperaceae	–	–	0.92	7.02	–	–	0.95	11.07	–	–	1.87	18.09
Macaranga marikoensis A.C.Smith	Euphorbiaceae	–	–	0.03	–	–	–	2.02	–	–	–	2.05	–
***Mikania micrantha* HBK**	Asteraceae	4.53	0.69	0.02	0.85	16.94	4.29	0.95	8.02	21.47	4.97	0.97	8.87
Momordica charantia L.	Cucurbitaceae	–	–	–	0.33	–	–	–	1.53	–	–	–	1.86
***Mucuna cochinchinensis* (Lour.) A. Chev.)**	**Fabaceae**	**1.69**	**0.29**	**0.48**	**0.19**	**10.16**	**7.14**	**7.97**	**1.53**	**11.85**	**7.43**	**8.44**	**1.72**
Paspalum conjugatum P.J. Bergius	Poaceae	–	0.32	3.40	0.76	–	4.29	8.92	8.02	–	4.60	12.32	8.77
Paspalum paniculatum L.	Poaceae	–	–	1.15	–	–	–	2.97	–	–	–	4.12	–
Passiflora foetida L.	Passifloraceae	0.54	0.05	–	–	1.69	1.43	–	–	2.23	1.48	–	–
***Physalis angulata* L.**	**Solanaceae**	**0.23**	**0.90**	**0.02**	**0.14**	**5.08**	**11.43**	**0.95**	**3.24**	**5.31**	**12.33**	**0.97**	**3.39**
Psidium guajava L.	Myrtaceae	–	–	0.10	–	–	–	3.92	–	–	–	4.02	–
Senna occidentalis (L.) Link.	Fabaceae	0.69	0.00	–	–	5.08	–	–	–	5.77	–	–	–
Setaria barbata Kunth.	Poaceae	64.18	68.26	1.83	–	11.86	17.14	3.92	–	76.04	85.41	5.75	–
Setaria pumila (Poir.) Roem. & Schult.	Poaceae	–	–	0.02	–	–	–	–	–	–	–	–	–
Sida acuta Burm.f.	Malvaceae	–	–	0.03	–	–	–	2.02	–	–	–	2.05	–
Solanum americanum Mill.	Solanaceae	0.08	–	–	–	1.69	–	–	–	1.77	–	–	–
Spermacoce remota Lam.	Rubiaceae	–	–	0.02	–	–	–	0.95	–	–	–	0.97	–
***Sphagneticola trilobata* (L.) Pruski**	**Asteraceae**	–	–	–	**57.04**	–	–	–	**14.31**	–	–	–	**71.35**
Stachytarpheta cayennensis (Rich.) Vahl	Verbenaceae	–	–	–	1.04	–	–	–	4.77	–	–	–	5.81
Thunbergia alata Bojer ex Sims	Acanthaceae	6.00	–	–	–	1.69	–	–	–	7.69	–	–	–
Urena lobata L.	Malvaceae	–	–	0.07	–	–	–	2.02	–	–	–	2.09	–
Urochloa mutica (Forssk.) T.Q. Nguyen	Poaceae	4.00	–	0.07	2.28	3.39	–	0.95	4.77	7.38	–	1.02	7.05

Table 2. Data showing the relative density (RLD), relative frequency (RLF) and importance value (IPV) of weeds species in a taro crop in Mua, Matei, Vione and Delaivuna, Taveuni Island at three months after planting. The bolded data represent the species that were present in all the four sites and the most dominant in each site.

		RLD (%)				RLF (%)				IPV			
Weed species	**Family**	**Mua**	**Matei**	**Vione**	**D/vuna**	**Mua**	**Matei**	**Vione**	**D/vuna**	**Mua**	**Matei**	**Vione**	**D/vuna**
***Ageratum conyzoides* L.**	**Asteraceae**	–	–	**88.54**	**3.30**	–	–	**12.38**	**5.66**	–	–	**100.92**	**8.95**
Capsicum frutescens L	Solanaceae	–	0.20	–	–	–	1.75	–	–	–	1.96	–	–
Centrosema pubescens Benth.	Fabaceae	7.47	5.63	–	–	12.77	8.77	–	–	20.23	14.41	–	–
Coccinia grandis (L.) Voigt	Cucurbitaceae	–	5.63	–	–		12.28	–	–	–	17.91	–	–
Crassocephalum crepidioides (Benth.) S.M.	Asteraceae	3.93	7.04	0.26	–	10.64	12.28	4.13	–	14.57	19.32	4.38	–
***Cuphea carthaginensis* (Jacq.) MacBr.**	**Lythraceae**	–	–	**1.95**	**35.38**	–	–	**10.31**	**22.62**	–	–	**12.26**	**58.01**
Cyperaceae sp.	Cyperaceae	–	–	–	7.89	–	–	–	3.85	–	–	–	11.74
Digitaria setigera Roth ex Roem. & Schult.	Poaceae	23.58	–	2.27	–	10.64	–	6.19	–	34.21	–	8.46	–
Dioscoria bulbifera L.	Dioscoreaceae	–	0.40	0.02	–	–	1.75	3.09	–	–	2.16	3.11	–
Eleuranthera ruderalis (Sw.) Sch. Bip.	Asteraceae	–	15.69	1.19	–	–	17.54	3.09	–	–	33.24	4.28	–
Eleusine indica (L.) Gaertn.	Poaceae	–	–	1.95	1.42	–	–	10.31	9.50	–	–	12.26	10.93
Euphobia hirta L.	Euphorbiaceae	–	–	0.05	–	–	–	1.03	–	–	–	1.08	–
Hyptis pectinata (L.) Poit.	Lamiaceae	2.16	–	0.31	–	4.26	–	7.22	–	6.42	–	7.53	–
Ipomoea indica (Burm.f.) Merr.	Convolvulaceae	–	–	0.01	–	–	5.26	1.03	–	–	–	1.04	–
Kyllinga polyphylla Willd. ex Kunth.	Cyperaceae	–	–	0.12	12.81	–	–	5.16	9.50	–	–	5.28	22.31
Manihot esculenta (Crantz)	Euphorbiaceae	–	–	–	0.13	–	–	–	1.81	–	–	–	1.94
***Mikania micrantha* HBK**	**Asteraceae**	**4.52**	**2.41**	**0.23**	**0.06**	**12.77**	**3.51**	**4.13**	**1.81**	**17.28**	**5.92**	**4.36**	**1.87**
Mimosa pudica L.	Fabaceae	0.20	–	–	–	2.13	–	–	–	2.32	–	–	–
Momordica charantia L.	Cucurbitaceae	–	–	–	0.71	–	–	–	3.85	–	–	–	4.56
Mucuna cochinchinensis (Lour.) A. Chev.)	Fabaceae	1.18	–	0.08	–	8.51	–	8.25	–	9.69	–	8.33	–
Paspalum conjugatum P.J. Bergius	Poaceae	–	–	0.15	25.87	–	–	1.03	15.16	–	–	1.18	41.03
Paspalum paniculatum L.	Poaceae	–	–	0.56	–	–	–	7.22	–	–	–	7.78	–
Passiflora foetida L.	Passifloraceae	–	0.80	–	–	–	1.75	–	–	–	2.56	–	–
Physalis angulata L.	Solanaceae	0.20	12.68	0.10	–	2.13	15.79	3.09	–	2.32	28.47	3.20	–
Psidium guajava L.	Myrtaceae	–	–	0.04	–	–	–	4.13	–	–	–	4.17	–
Senna occidentalis (L.) Link.	Fabaceae	1.38	–	–	–	8.51	–	–	–	9.89	–	–	–
***Setaria barbata* Kunth.**	**Poaceae**	**42.44**	**49.50**	**2.10**	**0.06**	**19.15**	**19.30**	**6.19**	**1.81**	**61.58**	**68.80**	**8.29**	**1.87**
Setaria pumila (Poir.) Roem. & Schult.	Poaceae	–	–	0.01	–	–	–	1.03	–	–	–	1.05	–
Spermacoce remota Lam.	Rubiaceae	–	–	0.05	–	–	–	1.03	–	–	–	1.08	–
Sphagneticola trilobata (L.) Pruski	Asteraceae	–	–	–	11.84	–	–	–	16.97	–	–	–	28.81
Stachytarpheta cayennensis (Rich.) Vahl	Verbenaceae	–	–	–	0.06	–	–	–	1.81	–	–	–	1.87
Thunbergia alata Bojer ex Sims	Acanthaceae	5.50	–	–	–	2.13	–	–	–	7.63	–	–	–
Urochloa mutica (Forssk.) T.Q. Nguyen	Poaceae	7.47	–	–	0.45	6.38	–	–	5.66	13.85	–	–	6.11

indicated that the only two species that were present in all the four study sites were *C. crepidioides* and *S. barbata* (Table 3). However, in Mua, para grass (*Urochloa mutica* (Forssk.) T.Q. Nguyen) was the most dominant species at 72.7% IPV and RLD value of 55.7% and RLF of 17.0%. In Matei, *S. barbata* was the most dominant with 123.1% IPV and RLD and RLF values of 96.5% and 26.7%, respectively (Table 3). In Vione, A. conyzoides remained the most dominant as in one and three months after planting with an IPV value of 101.8%, while in Delaivuna, nut sedge (*Cyperus rotundus*) was the most dominant with an IPV value of 61.6% (Table 3).

The analysis of data on the average IPV to determine the top five weed species on taro crops in Taveuni at 1, 3 and 6 months after planting demonstrated that *S. barbata* was the most dominant in taro followed by *A. conyzoides, C. carthaginensis, C. crepidioides* and *S. trilobata* (Table 4). The top four weed species were present throughout the growing stages of taro from planting to harvesting.

4.0 DISCUSSION

A large number of weed species have been associated with taro production in Fiji. For instance, the present study recorded a total of 46 weed species belonging to 20 plant families. In a similar study on taro cultivation in eastern Viti Levu in 2008 showed that a total of 57 weed species belonging to 26 plant families were recorded in taro farms in Serua, Naitasiri and Tailevu Provinces (Macanawai *et al.* 2010). Furthermore, the top five plant families were Asteraceae (11 species), Poaceae (10), Fabaceae (4), Euphorbiaceae and Solanaceae (3 each) (Macanawai *et al.* 2010). Interestingly, in the present study the same five plant families recorded the top five highest numbers of species but Poaceae was apparently the most dominant. The two top plant families in the two weed surveys on taro studies, that are Asteraceae and Poaceae, are known to be rich in plant species that are considered agricultural weeds (Heywood 1989; Tamado and Milberg 2000).

This study has shown that *S. barbata* was the most dominant weed species throughout the six months growing period of taro in Mua and Matei which are located at the northern part of the island. Even after herbicide applications for weed control at a month and four months after planting, the species maintained its dominance by occurring frequently in high density throughout the growing period of taro in the two sites. *Setaria barbata* was heavily infesting taro in the northern part of Taveuni as compared to the southern part of the island which was dominated by broadleaf weeds. This may suggest that the micro-environmental condition exists in the northern part of Taveuni may be more suitable for *S. barbata* i.e. Poaceae family or the species is more adaptable to the prevailing condition in the north than in the southern part of the island. A weed management trial conducted on intercropping of kava (*Piper methysticum* L.) and taro under coconut (*Cocos nucifera* L.) at Navakawau in south Taveuni in 1999-2000 showed that out of the nine weed species recorded on the site, only one species, T grass (*Paspalum conjugatum* P.J. Bergius) belong to the Poaceae family while the rest were broad-leaf weed species (Seniloli and Sharma 2008).

In Vione, *A. conyzoides* dominated the site with IPV values of 63%, 101% and 102% at first, three and six months after planting, respectively. This indicates that despite the management of weeds practised, *A. conyzoides* was able to increase its density and frequency resulted in the increase of its IPV throughout the growing stages of taro. Similar weed survey on taro in Tailevu and Serua Provinces recorded *A. conyzoides* as the most dominant weed species in taro (Macanawai *et al.* 2010). Furthermore, this suggests that *A. conyzoides* may have a very large viable soil seed bank and efficient recruitment strategies.

In Delaivuna, *S. trilobata, C. carthaginensis* and *C. rotundus* were the most dominant at first, third and six months after planting, respectively. The presence of *S. trilobata* in taro cultivation in Taveuni should be of great concern to farmers as it has the potential not only to invade and colonise agriculture production areas but the availability of a recommended herbicide and its high cost should be strongly considered (Macanawai 2007; Macanawai 2013).

This study has recorded for the first time the composition of weed species including their density, frequency and importance value on taro cultivation in Taveuni. However, in 1999-2000, Seniloli and Sharma (2008) recorded a weed spectrum of nine species on a kava intercrop with taro under coconut at a single site in Navakawau. The weed species reported in that study include, *Mikania micrantha* HBK., *A.conyzoides, P. conjugatum, Mimosa pudica* L. and *Stachytarpheta cayennensis* (Rich.) Vahl which were also found in the present study in Delaivuna, a neighbouring farming community.

Table 3. Data showing the relative density (RLD), relative frequency (RLF) and importance value (IPV) of weeds species in a taro crop in Mua, Matei, Vione and Delaivuna, Taveuni Island at six months after planting. The bolded data represent the species that were present in all the four sites and the most dominant in each site.

		RLD (%)				RLF (%)				IPV			
Weed species	**Family**	**Mua**	**Matei**	**Vione**	**D/vuna**	**Mua**	**Matei**	**Vione**	**D/vuna**	**Mua**	**Matei**	**Vione**	**D/vuna**
***Ageratum conyzoides* L.**	**Asteraceae**	–	–	**85.96**	**7.25**	–	–	**15.87**	**11.54**	–	–	**101.83**	**18.79**
Axonopus compressus (Sw.) Baeuv.	Poaceae	–	–	–	0.16	–	–	–	1.92	–	–	–	–
Blechum pyramidatum (Lam.)	Acanthaceae	–	–	–	0.16	–	–	–	1.92	–	–	–	2.08
Centrosema pubescens Benth.	Fabaceae	11.64	1.71	–	–	21.28	20.00	–	–	32.92	21.71	–	–
Coccinia grandis (L.) Voigt	Cucurbitaceae	–	0.41	–	–	–	6.67	–	–	–	7.08	–	–
***Crassocephalum crepidioides* (Benth.) S.M.**	**Asteraceae**	**1.60**	**0.05**	**0.01**	**1.65**	**10.64**	**2.22**	**1.59**	**5.77**	**12.24**	**2.27**	**1.60**	**7.42**
Cuphea carthaginensis (Jacq.) MacBr.	Lythraceae	–	–	1.97	25.86	–	–	17.45	21.17	–	–	19.42	47.04
***Cyperus rotundus* L.**	**Cyperaceae**	–	–	**0.28**	**48.11**	–	–	**3.18**	**13.46**	–	–	**3.46**	**61.57**
Digitaria setigera Roth ex Roem. & Schult.	Poaceae	10.27	–	–	–	8.51	–	–	–	18.78	–	–	–
Eleuranthera ruderalis (Sw.) Sch. Bip.	Asteraceae	–	0.28	0.00	–	–	8.89	1.59		–	9.16	1.59	–
Eleusine indica (L.) Gaertn.	Poaceae	0.23	–	11.14	0.16	2.13	–	19.05	1.92	2.36	–	30.19	2.08
Euphobia hirta L.	Euphorbiaceae	–	–	0.01	–	–	–	3.18	–	–	–	3.18	–
Hyptis pectinata (L.) Poit.	Lamiaceae	0.46	–	0.01	–	4.26	–	1.59	–	4.71	–	1.59	–
Ipomoea indica (Burm.f.) Merr.	Convolvulaceae	–	0.05	0.01	–	–	2.22	1.59	–	–	2.27	1.59	–
Kyllinga polyphylla Willd. ex Kunth.	Cyperaceae	–	–	0.01	0.49	–	–	3.18	1.92	–	–	3.18	2.41
Lindernia rotundifolia (L.)	Scrophulariaceae	–	–	–	0.16	–	–	–	1.92	–	–	–	2.08
Mikania micrantha HBK	Asteraceae	0.23	0.09	–	–	2.13	4.45	–	–	2.36	4.54	–	–
Mimosa pudica L.	Fabaceae	0.23	–	–	–	2.13	–	–	–	2.36	–	–	–
Mucuna cochinchinensis (Lour.) A. Chev.)	Fabaceae	0.68	0.28	–	–	6.38	13.33	–	–	7.07	13.61	–	–
Paspalum conjugatum P.J. Bergius	Poaceae	–	0.37	–	0.66	–	4.45	–	3.86	–	4.81	–	4.51
Paspalum paniculatum L.	Poaceae	–	–	0.02	–	–	–	6.35	–	–	–	6.37	–
Phyllanthus amarus Sch. & Thon.	Euphorbiaceae	–	–	–	0.16	–	–	–	1.92	–	–	–	2.08
Physalis angulata L.	Solanaceae	–	0.28	0.00	0.99	–	8.89	1.59	5.77	–	9.16	1.59	6.76
Polygala paniculata L.	Polygalaceae	–	–	–	0.16	–	–	–	1.92	–	–	–	2.08
Psidium guajava L.	Myrtaceae	–	–	0.01	–	–	–	4.76	–	–	–	4.77	–
Senna occidentalis (L.) Link.	Fabaceae	0.91	0.05	–	–	6.38	2.22	–	–	7.30	2.27	–	–
***Setaria barbata* Kunth.**	**Poaceae**	**17.81**	**96.45**	**0.07**	**0.16**	**17.02**	**26.67**	**7.94**	**1.92**	**34.83**	**123.12**	**8.01**	**2.08**
Setaria pumila (Poir.) Roem. & Schult.	Poaceae	–	–	0.46	–	–	–	4.76	–	–	–	5.22	–
Spermacoce remota Lam.	Rubiaceae	–	–	0.00	0.16	–	–	3.18	1.92	–	–	3.18	2.08
Sphagneticola trilobata (L.) Pruski	Asteraceae	–	–	–	12.52	–	–	–	17.32	–	–	–	29.84
Stachytarpheta cayennensis (Rich.) Vahl	Verbenaceae	–	–	–	1.15	–	–	–	3.86	–	–	–	5.01
Thunbergia alata Bojer ex Sims	Acanthaceae	0.23	–	–	–	2.13	–	–	–	2.36	–	–	–
Urena lobata L.	Malvaceae	–	–	0.00	–	–	–	1.59	–	–	–	1.59	–
***Urochloa mutica* (Forssk.) T.Q. Nguyen**	**Poaceae**	**55.71**	–	–	–	**17.02**	–	–	–	**72.73**	–	–	–

Table 4. Average importance value (IPV %) of the top five weed species on taro crops in Taveuni at 1, 3 & 6 months after planting

Weed species	Family	Average Importance value (IPV %)		
		1 month	3 months	6 months
Setaria barbata Kunth.	Poaceae	42	35	42
Ageratum conyzoides L.	Asteraceae	21	27	30
Cuphea carthaginensis (Jacq.) MacBr.	Lythraceae	20	18	17
Crassocephalum crepidioides (Benth.) S.M.	Asteraceae	12	10	6
Sphagneticola trilobata (L.) Pruski	Asteraceae	18	–	7

Figure 3. The most common weed of taro in Taveuni. Bristly foxtail grass (*Setaria barbata*).

Figure 5. Tarweed (*Cuphea carthaginensis*), one of the top five common weeds of taro in Taveuni.

Figure 4. Goatweed (*Ageratum conyzoides*), one of the top five common weeds of taro in Taveuni.

Figure 6. Thickhead (*Crassocephalum crepidioides*) one of the top five weeds of taro in Taveuni.

Figure 7. Wedelia (*Sphagneticola trilobata*), one of the top five common weeds of taro in Taveuni.

This may suggest that these species are common in the southern region of Taveuni. The present study has revealed the top five weed species on taro in the island, *S. barbata* was the most dominant weed species on taro, followed by three species of Asteraceae; *A. conyzoides, C. crepidioides, S. trilobata* and a single species of Lythraceae (*C. carthaginensis*) (Table 4).

According to Smith (1979), *S. barbata* occurred from sea level to about 200 masl and is commonly found in forest clearings, plantations, and along roadsides in Fiji. *Setaria barbata* was found in the main islands which includes Viti Levu, Vanua Levu, Taveuni, Ovalau and Koro Island (Smith 1979). Similar results have been reported on legume crop production in the Cameroon where *S. barbata* and *A. conyzoides* were the most serious weed species with >100 plants m^{-2} (Ngouagio and Daelemans 1991). In addition, *S. barbata* has been reported as a host for Maize streak virus, a serious and important viral disease on maize in sub-Saharan Africa (Oluwafemi *et al.* 2007). The present study revealed that all except one species found on taro is non-native to Fiji. This shows that these species have naturalised and has adapted to the micro-environment existed in taro cultivation on the island.

With more than 40 weed species representing 20 different plant families infesting taro cropping areas in Taveuni Island signifies high weed species diversity. The diversity of weed species in cultivated areas reflects the response of weed species to soil management (Dorado and Lopez-Fendo 2006). Attributed to the geographical features and soil condition, minimum tillage and the use of herbicides for weed management as commonly practised by taro farmers in Taveuni (Waisea Railumu, Agriculture Extension Office-Taveuni, *pers. comm.* 27 May 2013). This might have contributed to the diverse weed species composition and high weed density in cultivated areas. It is known that zero- and minimum-tillage produce high weed species richness and diversity as compared to tillage system (Thomas *et al*. 2004; Dorado and Lopez-Fendo 2006; Shemdoe *et al.* 2008). Furthermore, the overuse of inorganic chemical fertilizers on monocrop taro cultivation may have contributed to soil health problems and high weed infestation in Taveuni (Halavatau *et al.* 2013). This is concurred with Wezel (2000) and Shemdoe *et al.* (2008), that the shift from short cultivation–long fallow periods to short cultivation–short fallow periods or permanent cropping have resulted in high weed infestation and soil degradation.

This present study has enhanced our knowledge and understanding of the weed spectrum and in particular the most dominant weed species in taro production in the study sites in Taveuni. The persistence of some weed species in the midst of two contact herbicide applications may indicate the substantial amount of viable weed seeds in the soil seed bank and perhaps the potential resistance of some species to the paraquat herbicide in taro production areas. The distinct variation in the dominance of Poaceae species like *S. barbata* in the northern region and broadleaf weeds in the southern region of Taveuni provides a strong evidence to review the weed management practices on taro production in the two regions.

Further studies to include the weed survey in the central region of the island and compare the weed spectrum in different altitudes in the three regions would aid our understanding on the composition of weed species in taro production in Taveuni relative to altitudes and regions.

ACKNOWLEDGEMENTS

I sincerely thank the ACIAR's funded 'Improving Soil Health in Support of Sustainable Development in the Pacific' project for allowing me to undertake this study on their taro trial sites in Taveuni, the Secretariat of the Pacific Community and FAO's TCP for the financial support and to Selveena Lal and Meleki Motu at Plant Protection Section, Koronivia Reseach Station; Mikaele Raivalita, Jovesa Nawaqa, Joseva Vakabua, Ilaisa Moce and Paul William at Taveuni Research and Development Centre, Taveuni for their assistance in the fieldwork. I also thank Dr R.C. Joshi for his comments on the manuscript.

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SHORT NOTE

The comparative efficacies of male aggregation pheromones on coconut rhinoceros beetle (*Oryctes rhinoceros* L.) in Viti Levu, Fiji

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ABSTRACT

Coconut rhinoceros beetle (*Oryctes rhinoceros* L.), still remains a very serious insect pest of coconut palms in many Southeast Asia and Pacific Island countries and territories, even after the successful introduction of the virus, *Oryctes nudivirus* (OrNV) (Huger) and an entomopathogenic fungus, *Metarhizium anisophilae* (Metsch.). The use of male aggregation pheromones is an essential tool for incursion detection and monitoring, and also for the management of this invasive pest beetle populations in the Pacific Island countries and territories. Male aggregation pheromones for *O. rhinoceros* are commercially available in many countries. Thus, it is important to evaluate their comparative efficacies. The findings from this research investigation will benefit biosecurity officers, farmers and researchers in dealing with *O. rhinoceros* incursions to manage it in a most efficient and effective manner. Three male aggregation pheromones (two from Russell IPM of United Kingdom and one from ChemTica Internacional of Costa Rica), were compared for the adult beetle attraction efficacies of *O. rhinoceros* in Viti Levu Island of the Republic of Fiji. The field evaluation trial was carried out from July to December 2013. We found out that the Costa Rica aggregation pheromone out-performed the one from Russell IPM of United Kingdom.

Key words: Coconut rhinoceros beetle, *Oryctes rhinoceros,* male aggregation pheromones, field efficacy, management, Republic of Fiji.

1.0 INTRODUCTION

Coconut rhinoceros beetle, (*Oryctes rhinoceros* L.), Coleoptera: Scarabaeidae, is an exotic insect pest of coconut (*Cocos nucifera* L.) that had been reported in the Pacific region for more than a century. It has continued to be a serious invasive pest to coconut palms. Other recorded host plants are oil palm (*Elaeis guineensis* Jacq.), betel nut (*Areca catechu* L.), Pandanus species, sugarcane (Saccharum *officinarum* L.) and pineapple (*Ananas comosus* (L.) Merr.) (Lever 1979; Smith and Moore 2008). *O. rhinoceros* L. is native to the South Asian region (Gopal et al. 2001). It was first introduced into Samoa from Sri Lanka in 1909 (Doane 1913; Gressitt 1953). Since then it has spread to other Pacific Island countries and territories (PICTs) including Tonga in 1921, Wallis in 1931, Palau in 1942, Papua New Guinea in 1942, Fiji in 1953, Tokelau in 1964, and Guam in 2007 (Tokelau 2005; Jackson 2012). The adult beetles of *O. rhinoceros* are destructive to the palms, and other host plants (Schmaedick 2005). Adult beetles take nocturnal flights to the palms and chew down holes into folded emerging fronds, and feed on sap of flowers. Adult beetles are gregarious and usually aggregate at feeding and breeding sites.

Therefore, quite often more than one beetle may attack a given palm at the same time, while the neighbouring tree may be spared from being attacked (Gressitt 1953; Zelazny and Alfiler 1991). This aggregation behaviour may occur either because of the male aggregation pheromone or as effects of the host plant chemicals (kairomones) (Hallett 1996). Infested palms may either be killed or inflicted with severe loss of leaves leading to reduction of nut setting. Wounds resulting from the adult feedings may also serve as infection pathways for pathogens or other pests (Surany 1960). The effects of adult boring may be more severe on younger palms where spears are narrower. Wedge-shaped area or V-shaped cuts visible on the host palms is an easy way of determining adult beetle presence in the plantation (Smith and Moore 2008).

Oviposition and larval development of *O. rhinoceros* occur in moist organic materials such as sawdust, manure, compost and garbage heaps, or above ground in tunnels, debris in axils of coconut fronds, in still standing but dead and rotten coconut palms, and in the rotten ends of fallen coconut trunks (Schmaedick 2005). According to Gressitt (1953), under optimal conditions, eggs can take 11-13 days to hatch, while larvae pass through 3 moulting stages lasting from 80 to 130 days, and pupal period 16-24 days; male adult beetles live for about 90 days, while females live for about 100 days and lay about 90 eggs. The adult beetles live on fresh sap from host palms (Surany 1960; Jackson 2013).

Coconut and oil palms are very important crops in terms of food and nutrition security, cultural and economical values in PICTs. Thus, biosecurity awareness and surveillance in PICTs and national boundaries that are still free of this pest is of paramount importance.

The use of aggregation pheromones that are produced by males of *O. rhinoceros* attracts both males and females, are an important monitoring tool for its surveillance and also for the delimiting surveys (Pacific Islands Report 2002; Moore 2008). These pheromones are usually attached to the bucket traps. There are two kinds of bucket traps commonly used. They are vaned bucket trap and closed bucket with entrance holes (2 cm diameter) on the lid and upper side wall. These bucket traps are usually hung between 1.5 – 2.0 m above from the ground surface (Figure 2). It has been reported that the vaned bucket traps captures more adult beetles, than the closed buckets (Hallett *et al*. 1999).

For effective management of *O. rhinoceros* a combination of control options are needed, such as mechanical, biological and chemical methods. Mechanical methods include field scouting and physical removal of beetles from the infested trees, destructions of breeding sites, and killing of adult beetles that are attracted to lights in the residential houses. The use of chemical should be used as the last option and may involve the use of hazardous insecticides that can be drenched on breeding sites to kill both adults and juvenile stages (eggs, larvae and pupae), and napthalene balls and oil cakes of neem on palm crowns to repel the adult beetles (Howard *et al*. 2001). Male aggregation pheromone, when used in buckets traps are also useful in reducing beetle populations in plantations (Norman and Basri 2004; Oehlschlager 2007). The main biological control agents are a virus (*Oryctes nudivirus* (OrNV)) (Huger) originally from Malaysia and an entomopathogenic fungus, *Metarhizium anisopliae* (Metsch.) reported from the Philippines (Jackson 2013).

This research evaluated the bio-efficacy of three commercially available male aggregation pheromones. They were purchased from two companies: two formulations from Russell IPM, United Kingdom, and one formulation from ChemTica Internacional, Costa Rica.

The field evaluation was carried out by the Plant Protection staff of the Secretariat of the Pacific Community (SPC), in collaboration with the Plant Protection staff of Koronivia Research Station of the Ministry of Agriculture, Republic of Fiji.

2.0 MATERIALS AND METHODS

2.1 *Study site*

Twenty coconut plantations along the highway around Viti Levu were selected for the study (Fig. 1). Treatments were replicated in each coconut plantation. Trial sites were selected on the visibility of high adult beetle characteristic V-shaped damage.

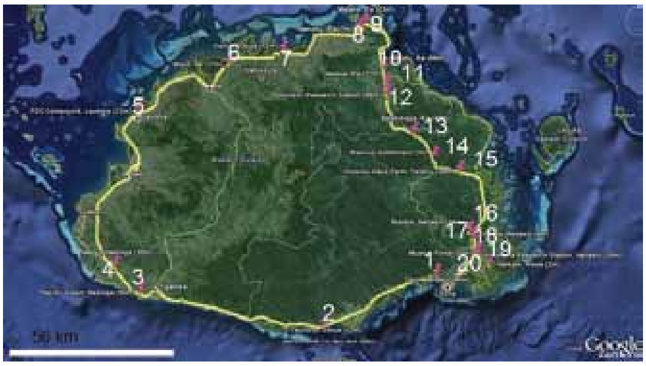

Figure 1. Locations of trap sites around Viti Levu, Fiji. (The numbers represent the following locations: 1. Lami, 2. Taunovo, 3. Pacific Green, 4. Nabau, 5. FSC, 6. Bilolo, 7. Kavuli, 8. Nanuku, 9. Rakiraki, 10. Barotu, 11. Nalawa, 12. Dobuilevu, 13. Balekinaga, 14. Wainivo, 15. Korovou dairy, 16. Waidra, 17. Vereta, 18. Muana, 19. Nakaile, 20. Koronivia). Source: Google map.

2.2 *Treatments and design*

Three commercially available male aggregation pheromones were evaluated in the field for the comparative olfactory responses on the coconut rhinoceros beetle, *Oryctes rhinoceros.* Two of the male aggregation pheromones manufactured by Russell IPM of United Kingdom were: (1) *Oryctes rhinoceros* PH-672-1PE – Batch No. 62/9550, Manufacturing date: September 2012, Expiry date: September 2014, (referred in this paper as Russell IPM UK 1) and, (2) *Oryctes rhinoceros* PH-672-1PE – Batch No. 63/1033, Manufacturing date: February 2013, Expiry date: February 2015 (referred in this paper as Russell IPM UK 2). The cost of one sachet of both UK pheromones was US$5.92. The other pheromone was manufactured by ChemTica Internacional in Costa Rica (referred in this paper as Costa Rica) and costed US$3.50 per sachet. The pheromones traps were installed on 25th July 2013.

Closed bucket with three small holes (2.5 cm diameter) as entrances for beetles on both the lid and topside of the bucket wall (Figures 2 & 3) were used.

At each trapping site, each of the three pheromones were placed separately in the individual plastic buckets of same colour. Each bucket had three holes (2.5 cm diameter) on the top side wall, and three entrance holes (2.5 cm diameter) on the lid. The sealed airtight sachet of respective pheromones were cut open using a scissor and the plastic sachet with pheromone removed from the cover and suspended with a wire loop in the middle of the bucket lid.

The size and volume of sachets of all the three pheromones were all the same (Fig. 4). In the plantation at each site, the three pheromone treatments were placed in a triangular design 50 m apart and hung about 2 m above ground on a tree branch. Tie-wires were used to tie the bucket holder onto the tree branch. Tangle-foot (sticky paste) was smeared around the bucket holder to avoid ants and other predators entering the bucket.

Cross contamination between pheromone traps were avoided by assigning only one person handling one pheromone type throughout any one trip when installing, monitoring and servicing the traps. Male aggregation pheromones in all the trap sites were replaced on 15th November 2013.

2.3 *Trial assessments*

Assessments of the traps were carried-out at every three to four weeks intervals from the time the traps were initially installed (July 2013). Records on the number of adult beetles trapped and their sex, were counted and recorded on each assessment date. Other information that were

Figure 2. A coconut rhinoceros beetle trap installed on a bread fruit tree in the middle of a coconut plantation, at the trap site, Toga Village, Fiji.

Figure 3. Adult Beetles observed to be trapped in the closed bucket trap, during assessment date.

Figure 4. Sachets of the three male aggregation pheromones evaluated.

recorded at the time when the traps were installed at the sites included the location, district, name of farmers or owners of coconut plantation, status of sanitation of plantation, total number of leaves per palm, number of leaves damaged per palm, number of nut bunches per palm, and total number of nuts per bunch.

3.0 RESULTS

3.1 *Trial Assessment*

The mean number of *O. rhinoceros* adult beetles attracted and trapped inside the buckets of the three male aggregation pheromones was significantly different ($F_{2, 237} = 35.99$, $P < 0.0001$). Costa Rica pheromones trapped significantly more adult beetles, compared to those from Russell IPM, UK (Fig. 5). No significant differences were observed between adult beetle capture rates on traps baited with Russell IPM, UK1 and Russell IPM, UK 2 pheromones with not a single adult beetle caught on Russell IPM, UK 1 (Fig. 5). Significant differences were observed in the mean number of males and females trapped ($t = 3.511$; $P < 0.001$). Overall more female beetles were trapped than the male beetles (Fig. 6).

There were significant differences in the mean number of adult beetles caught at the different sites ($F_{19, 220} = 1.96$; $P < 0.01$) (Fig. 7). Such difference may have been due to unknown factors, such as nearby breeding site availability and others.

No significant differences in the mean number of adult beetles caught at different monitoring or checking times ($F_{3, 236} = 1.412$; $P = 0.24$). However, there were significant more mean number of female beetle than male beetles caught in the traps($t = -3.511$), ($P<0.05$).

3.2 *Damage assessment*

Damage assessments at the trapping sites were taken to gauge the level of damage in relation to the number of adult beetles that were trapped within the total duration of the trial (July to December 2013). The average percentage of the number of leaves per site and the average number of nuts per palm at each site were essentially the target of assessments.

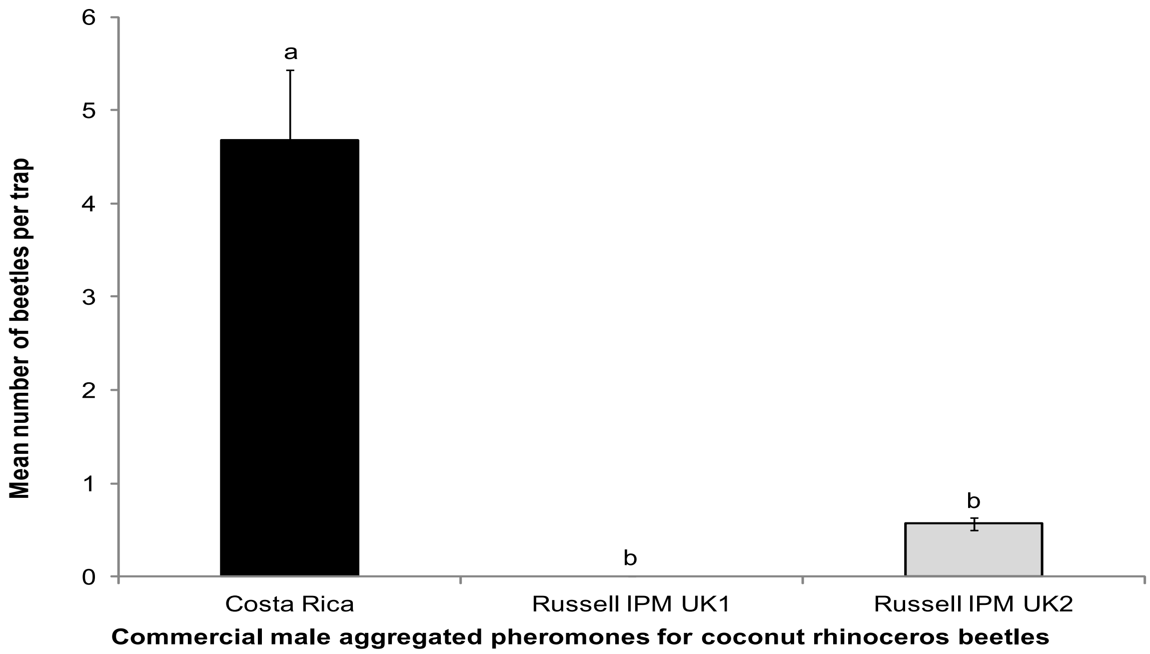

Figure 5. Comparative attraction of coconut rhinoceros adult beetles per trap, July to December 2013, Fiji. (Differences in letters indicate significant efficacy differences between pheromones evaluated).

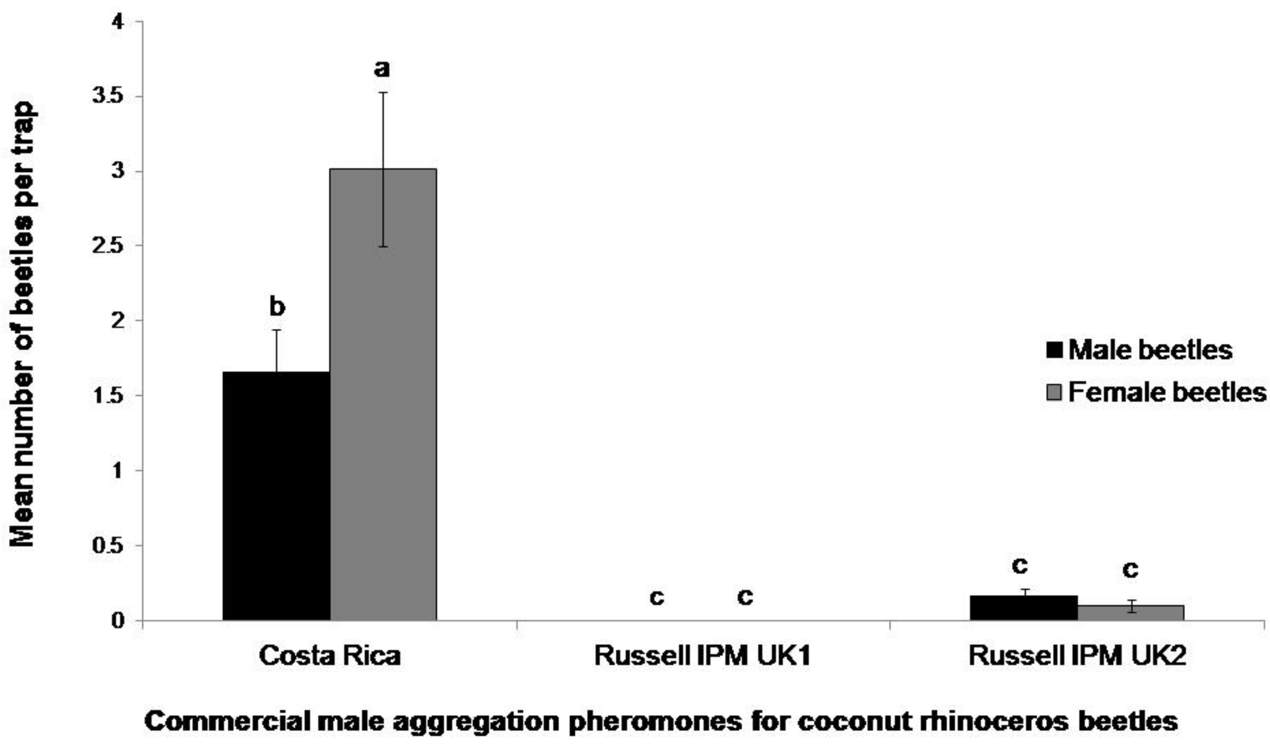

Figure 6. Comparative attraction of the adult beetle sexes to three male aggregation pheromones evaluated, July to December 2013. Fiji. (Differences in letters indicate significant efficacy differences between pheromones).

Table 1. Coconut leaf damages and nut yields assessed before male aggregation pheromone traps were placed at trap sites.

Trap No.	Trap site	District	Av. No. Leaves /palm	Total No. Leaves	Total No. Leaves damaged	% Av. leaves damaged	Av. Nuts/ palm
1	Lami	Naitasiri	23	344	75	22	31
2	Taunovo	Serua	24	352	94	26	31
3	Pacific Green	Nadroga	16	233	204	87	2
4	Nabau	Nadroga	17	173	16	9	37
5	FSC	Lautoka	14	193	138	71	5
6	Bilolo	Ba	22	322	58	18	31
7	Kavuli	Tavua	13	116	29	25	8
8	Nanuku	Ra	20	198	59	30	20
9	Rakiraki	Ra	20	305	51	17	28
10	Barotu	Ra	20	294	39	13	21
11	Nalawa	Ra	20	141	60	43	23
12	Dobuilevu	Ra	22	323	38	18	43
13	Balekinaga	Ra	19	282	82	29	23
14	Wainivo	Tailevu	18	265	48	18	23
15	Korovou dairy	Tailevu	20	299	35	12	49
16	Waidra	Naitasiri	20	301	14	5	20
17	Vereta	Naitasiri	15	223	18	8	0
18	Muana	Rewa	18	272	84	31	15
19	Nakaile	Rewa	20	293	117	40	37
20	Koronivia	Naitasiri	20	334	45	14	38

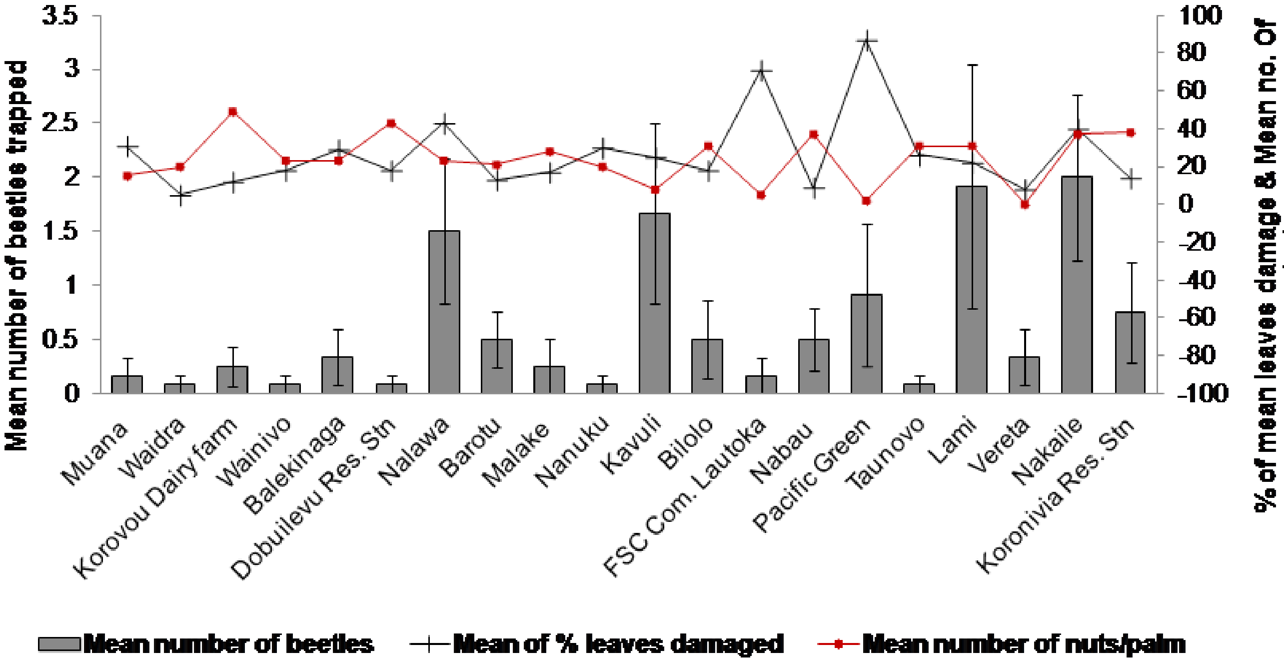

Figure 7. Mean number of adult beetles per trap, mean percentage of leaves damage, and mean number of nuts per palm at different sites around Viti Levu Island, July to December 2013.

4.0 DISCUSSION

The male aggregation pheromone (ethyl 4-methyloctanoate) found in male beetles of *O. rhinoceros* is made commercially available in many countries around the world, for monitoring population as well as controlling them in coconut and oil palm plantations. We therefore screened and assessed their comparative attraction efficacies against *O. rhinoceros* for end-users to monitor and manage this invasive insect pest.

In this trial, three male aggregation pheromones were evaluated for their attraction efficacies. Results have shown that there were significant differences in the levels of attraction efficacies between the three products tested. Oryctalure from ChemTica Internacional in Costa Rica was significantly more superior in attracting adult beetles, than the two products from Russell IPM in the United Kingdom. At Tokelau, similar results were obtained with no beetles attracted with Russell IPM UK 1 lure (Tofiga Teao *pers. comm.,* 12 December 2012).

Male aggregation pheromones are known to attract both males and females. However, results in this trial showed that more female beetles were attracted to the lure than the male beetles. From the observations, it suggested that in some sites where percentages of leaves damage were high, the number of beetles caught in the traps were low and vice versa (Fig. 7). Explanation of such pattern is difficult to interpret, thus suggesting the need for detailed scientific investigations. Coconut yields are expected to be less in sites where more beetles are caught and leaf damages are high. However, such expectations were not convincing to be the case in the results of this experimentation. The status of crop sanitation in the respective sites was suspected to contribute immensely to the status of damage and so was the number of adult beetles trapped. No proper field crop sanitation whatsoever were practiced in all the trap sites. However, there were sites that had cattle farms with unmanaged cow dung, sugarcane plantations with unattended heaps of molasses and coconut timber milling with saw dust refuse that provided breeding sites for the beetle.

Trap positions and directions of prevailing winds in relation to the direction of where more palms are situated in the plantations was suspected to contribute and determine beetle attraction to the traps. Also it was observed that traps placed at edges of plantations from incoming prevailing wind direction trapped more beetles than those placed in the opposite wind direction.

Finally, the trial has confirmed that the best male aggregation pheromone out of the three pheromones tested is the Costa Rica Oryctalure. Not only is it more attractive, but cheaper than those from Russel IPM UK.

ACKNOWLEDGEMENTS

The authors of this paper would like to convey a word of thanks to SPC LRD, especially respective coordinators of Plant Health (PH) and Biosecurity and Trade Services (BATS), and Ministry of Agriculture of the Republic of Fiji (Plant Protection of Koronivia Research Station), for approval and providing logistics and financial supports towards this trial. Thanks to Dr. Ravindra C. Joshi, Consultant and Dr. Apaitia Macanawai, Ministry of Agriculture, Republic of Fiji for the review and assist in editing this manuscript.

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SHORT NOTE

Efficacy of different rates of glyphosate treatments for the control of Jerusalem thorn (*Acacia concinna*) in Fiji

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ABSTRACT

Jerusalem thorn, *Acacia concinna* (Willd.) DC. is an introduced invasive thorny shrub that can form impenetrable thickets. Under heavy infestations, it can prevent livestock from grazing, prevent access to land, water and cause severe injuries to people. Determining a cost effective method of controlling this invasive species is necessary to reduce its impact on the environment and livelihoods of people in the infested areas. Three (3) treatments of glyphosate 360g/L rates were applied on slashed stems of *A. concinna* and their efficacies in preventing coppicing were assessed monthly for seven months following application. There were no significant differences in the efficacies between the three herbicide rates while zero glyphosate (control) was significantly the lowest. Glyphosate rate 1:1 (1 parts of glyphosate: 1 part of water) recorded the highest average efficacy at 90%, followed by 1:2 (84%), 1:3 (78%) and the lowest was no glyphosate (12%). Glyphosate rate 1:3 was the most cost-effective rate and is recommended for controlling *A. concinna* in Fiji.

Key words: *Acacia concinna,* glyphosate, Fiji, herbicidal control, invasive species.

1.0 INTRODUCTION

Acacia concinna (Willd.) DC. (Jerusalem thorn) (Fig. 1), belongs to the family Fabaceae. It is a thorny shrub, native to Asia (ISSG 2008) where the natural distribution range is from India to Southern China and east to Papua New Guinea. Countries in the native range where it is reported include Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Japan, Laos, Malaysia, Myanmar, Nepal, Philippines, Singapore, Taiwan and Vietnam (US Forest Services 2013; ILDIS 2014). Outside this native range it is invasive or regarded as a pest in Mauritius, on Mahe Island in Seychelles, Madagascar, and in the Pacific islands in New Caledonia (Orapa 2012, unpublished report to UNEP).

It was introduced into Fiji supposedly for chutney but probably also for its qualities as a natural shampoo – the leaves contain high levels of saponins and have long being used as natural hair cleanser in India (Smith 1985). In Fiji, it was first reported as *Mimosa bimucronata* (DC.) Kuntze in 1952 by Smith (1985) who wrote that "the most recent introduction was found in Labasa from seeds brought from India by a local merchant who claimed that good chutney is made from A. concinna pods". It now occurs on at least five major outbreak sites on the two main islands of Viti Levu and Vanua Levu.

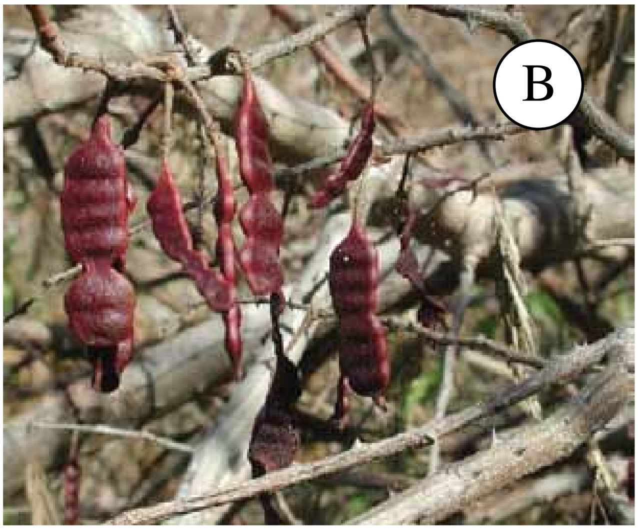

Figure 1. *Acacia consinna.* A) inflorescences, B) pods and C) growth habits at a sugarcane farm in Tavua, Viti Levu.

Acacia concinna is mainly propagated by seeds (US Forest Services 2013) but has the capacity to produce new shoots on some rooted creeping stems and exposed subterranean roots (A. Macanawai & W. Orapa *pers. obs.*)

This shrub can prevent farming on infested land and also prevent access to grazing areas and forests (A. Macanawai & W. Orapa *pers. obs*) and considered an invasive species (ISSG 2008). *Acacia concinna* has been found in rainforests, disturbed forest, open grasslands, fields and along creek sides from altitudes ranging from close to sea level to 1,050 m above sea level (Orapa 2012; US Forest Services 2013).

It forms thorny impenetrable tangled and creeping stem masses up to 8 m in height in open areas, which could not only cause injury to people but could smother other useful plants and prevent access to arable lands. In Fiji and New Caledonia infestations in open farmlands formed impenetrable scrambling thickets up to 10 m tall. In Seychelles, *A. concinna* was recorded to climb as high as 30 m into the canopy of large emergent secondary forest trees like *Albizzia moluccana* (Orapa 2012, unpublished report).

A collaborative programme between the Fiji Ministry of Primary Industry and the Secretariat of the Pacific Community (SPC) was developed in 2003 to delimit the extent of spread of *A. concinna* in Fiji and to identify control methods in eradicating this weed from infested areas. *Acacia concinna* was found to have localized and restricted infestations mainly on the periphery of sugarcane farms in Viti Levu and Vanua Levu. Trials to investigate the efficacy of different concentrations of the systemic herbicide Roundup (Glyphosate) were applied. This report outlines the outcomes of this research.

2.0 MATERIALS AND METHODS

2.1 *Study site*

The study site was located about 1.09 km (S17° 30' 35"; E177° 38' 57") from the Kings Road along the Varoko Cemetery Road at Varoka, Ba (Fig. 2). The *A. concinna* infestation occurred along a creek and covered an area of approximately 1 ha.

Figure 2. Satellite image of the location of the study site at Varoka, Ba, Viti Levu. Courtesy of Ms Aradhana Deesh. Source: Google map.

The site was surveyed and *A. concinna* base stems were identified and those with a diameter of 3 to 5 cm were selected. A total of 30 plants were selected for each treatment, totaling 120 plants freely rooted plants at the study site. The surrounding vegetation near each selected plant was cleared for easy access but not the foliage of the tagged plants. The tagged stems were slashed with a bush knife and two to three slits with about 3 cm deep were made on the freshly slashed stem before treatments were applied.

2.2 *Treatment preparation and application*

The herbicide concentrations used were 1:1 (i.e. 1 part of glyphosate 360g/L : 1 part of water); 1:2 and 1:3. Each treatment was prepared separately in a 1 L plastic bottle with a small hole on the lid for squarting the herbicide. For the control, the plants were cut but no chemical applied. The mixture was shaken properly to mix the solution properly before application.

2.3 *Data analysis*

Data on the efficacy of the treatments on each treated plant was recorded monthly for seven months. The data was arcsine transformed to satisfy the analysis of variance requirements and analysed using the STATISTICA 12 (StatsSoft®, Inc., USA). Analysis of variance (ANOVA) was conducted to determine the significance of treatments effects. The mean values were separated using the Fisher's Least Significant Difference test at 0.05.

3.0 RESULTS AND DISCUSSION

There was no significant difference in the efficacies of the four glyphosate rates between the 7 months the treatments were applied ($F_{(6,812)} = 0.07$, $P = 0.99$) (Fig. 3). This suggested that efficacy data recorded at one month after application of the four treatments was no different to that recorded at seven months later. Thus, to save costs treatments could be terminated a month after application of the first treatments.

The efficacy data at seven months following application of treatments showed that there is a significant difference in the efficacies between the four glyphosate rates ($F_{(3,116)} = 64.44$, $P < 0.001$). However, there was no significant difference in the efficacies between the three glyphosate rates while the control treatment was significantly the lowest (Fig. 3). Furthermore, treatment at equal glyphosate and water (1:1) recorded the highest average efficacy at 90%, followed by 1:2 (84%), and 1:3 (78%) while the control treatment was 12% (Fig. 4). Therefore, *A. concinna* could be controlled effectively by glyphosate rates 1:1; 1:2 and 1:3. The most cost-effective rate recommended is 1:3

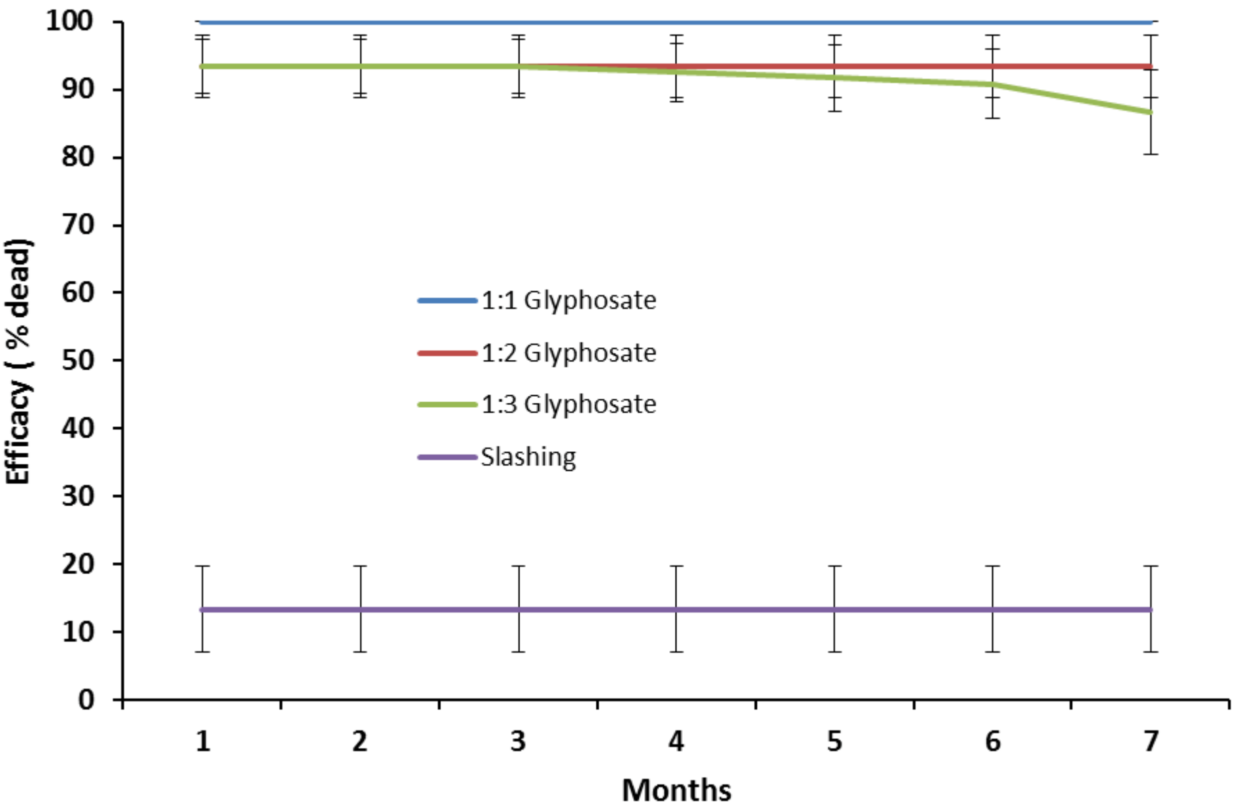

Figure 3. Efficacy (% of treated plants dead) of the four rates of glyphosate (1 = 1:1; 2 = 1:2; 3 = 1:3 and 4 = no glyphosate) from one to seven months after application.

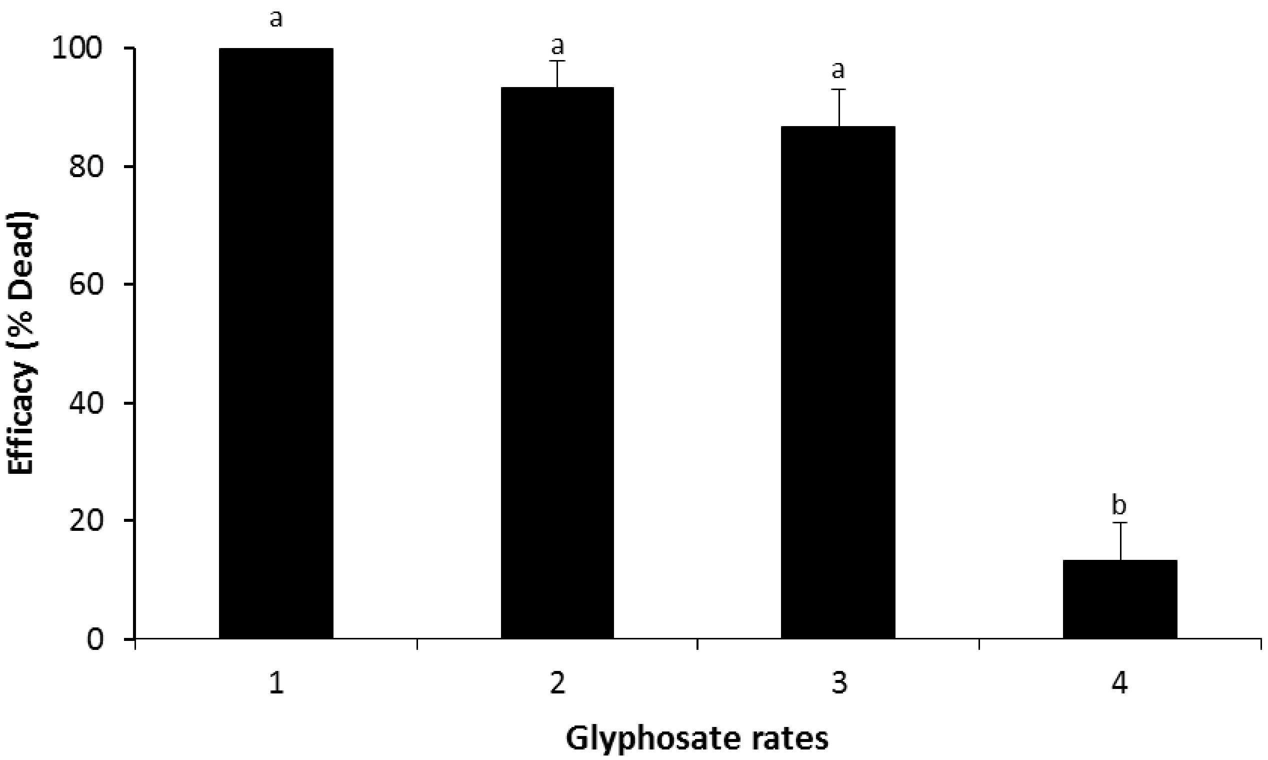

Figure 4. Efficacy (%) of the four rates of glyphosate (1 = 1:1; 2 = 1:2; 3 = 1:3 and 4 = no glyphosate) at seven months after application. Interval bars with the same letters are not significantly different at P< 0.05 and error bars show one standard error around the mean.

ACKNOWLEDGEMENT

We acknowledge the SPC Plant Protection Service for proving support for surveillance and eradication efforts. This work was not possible without the support of hardworking Koronivia Research Station staff, particularly Meleki Motu, Nitya Singh and Paras Reddy for their tireless efforts in the field.

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Bell, R. W. (1988). Nutrient deficiencies in four acid soils from southeast Viti Levu. *Fiji Agricultural Journal* 50, 7-13.

Book

Author(s)/editor(s), year of publication, title of book, volume (if applicable), publisher, place of publication. For example: Twyford, I.T. and Wright, A.C. (1965). The Soil Resources of the Fiji Islands. Fiji Government Printer, Suva.

Chapter in a book

Author(s), year of publication, title of chapter or article, title of book, editor(s), page numbers, publisher, place of publication. For example:
Fox, R.L. (1983). Sulfur accretions in soils of the tropics'. In: Sulfur in Southeast Asian and South Pacific Agriculture. (eds G.J.Blair and A.R. Till.)

pp. 39-53. Univ. of New England, Armidale.

Report/Bulletin
Author(s), year of publication, title of report, title of series, volume of series, place of publication.

For example:
Shepard, T.G. and Neall, V.E. (1986). Soil Taxonomic unit descriptions for Tutu Estate, Taveuni Island, Fiji. New Zealand Soil Taxonomic Soil Descriptions No. 13,Wellington.

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