Shade and coffee: a marriage made in heaven!

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ABSTRACT

Most smallholder coffee farmers in the PNG highlands grow their coffee under shade trees. Shade management is often inadequate because many farmers do not fully understand the benefits that well-managed shade trees can provide in terms of coffee productivity and provision of ecosystem services such as drought resilience, weed, pest and disease control, soil and water conservation, and nutrient cycling. Appropriate species of shade trees providing the correct shade level can also facilitate income diversification, increase labour efficiency and produce higher value, larger and denser coffee beans. Improved shade management will strengthen livelihood resilience in the face of climate change. However, a concerted extension effort by both the government and private sectors is required to inform smallholders of the economic and environmental benefits of effective shade management.

KEYWORDS: Shade; ecosystem services; income diversification; livelihood resilience; coffee extension

INTRODUCTION

Coffee is grown under shade to simulate the African forest environment in which it evolved (Alemu 2015). This is common practice in PNG with most smallholder coffee grown either over-shaded or under-shaded (Inu 2015; Curry et al. 2017). However, the value of well managed shade trees is not fully realised. Shade trees are a multidimensional resource for smallholders in terms of provision of ecosystem services, cost savings in production (particularly in labour), improvement in coffee bean quality and value, income diversification, and environmental sustainability (Beer 1987; Bote and Struik 2011; Jezeer et al. 2018). Growing shade trees as part of a coffee production system provides a mechanism to minimise livelihood risk and improve economic resilience (Gao 2018; Jezeer et al. 2018).

An absence of partnerships between farmers, processors and exporters and insufficient extension resources for coffee smallholders has meant that the advantages of effectively managed shade trees, and in particular the positive outcomes from research on the use of shade trees, have not been disseminated to growers. This paper investigates the condition of shade in smallholder coffee gardens and the level of knowledge amongst coffee smallholders of shade management practices and their purpose. We discuss how, with optimum management, shade trees can help enrich coffee farmers' lives in environmental, socio-cultural and economic terms. This will further highlight the necessity for support services for coffee growers, firstly, to enable them to produce good quality coffee and receive higher returns to labour while practising a low input system of production. Secondly, it will contribute to a more sustainable coffee industry for future generations.

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The benefits of effective shade cover in coffee production

Shade cover, at appropriate levels and using suitable trees, can provide many benefits to the coffee production system even with low levels of input. The benefits of shade have been recognised in the following domains:

1. Coffee tree physiology

Shade trees provide a buffer to coffee trees balancing metabolism and growth and extending their productive life. Under well managed shade, flowering occurs in more temporally concentrated windows rather than over extended periods which puts high nutritional demands on the coffee trees. Also, with appropriate shade, cherries mature at a slower rate resulting in larger bean size and improved bean quality (Bote and Struik 2011) (for a review see Beer 1987).

2. Ecosystem services and environmental sustainability

Shade trees provide a diversity of ecosystem services to the coffee production system which in turn contribute to the system's sustainability.

The physical environment

Shade trees buffer temperature extremes and abate the impacts of hail, heavy rain, and strong winds (Beer 1987; Vega et al. 2015). Wind erosion and related soil degradation is also moderated. The shade tree canopy aids in water conservation by decreasing water run-off, reducing nutrient leaching and soil erosion (Wallace 1997) and filters light thereby suppressing weed growth (De Silva and Tisdell 1990; Njoroge 1994).

Also assisting in weed suppression as well as soil moisture retention is mulch created by leaf fall and pruning residues from shade trees (Youkhana and Idol 2009). In addition, mulch increases soil organic matter and the diversity of soil microorganisms, decreases erosion and slows the rate of decomposition of soil organic matter (Beer 1987; Vega et al. 2015).

The rhizosphere

Shade tree root systems can improve soil drainage and aeration. Many species with extensive and deep root systems are able to access nutrients accumulated at depth and in time deliver them to the coffee trees via leaf fall and pruning residues (Figure 1). Nitrogen fixing shade trees (e.g. Casuarina and Albizia, the most common shade trees grown in PNG) will further supplement soil nutrient stocks (Beer 1987; Prabhakaran Nair 2010).

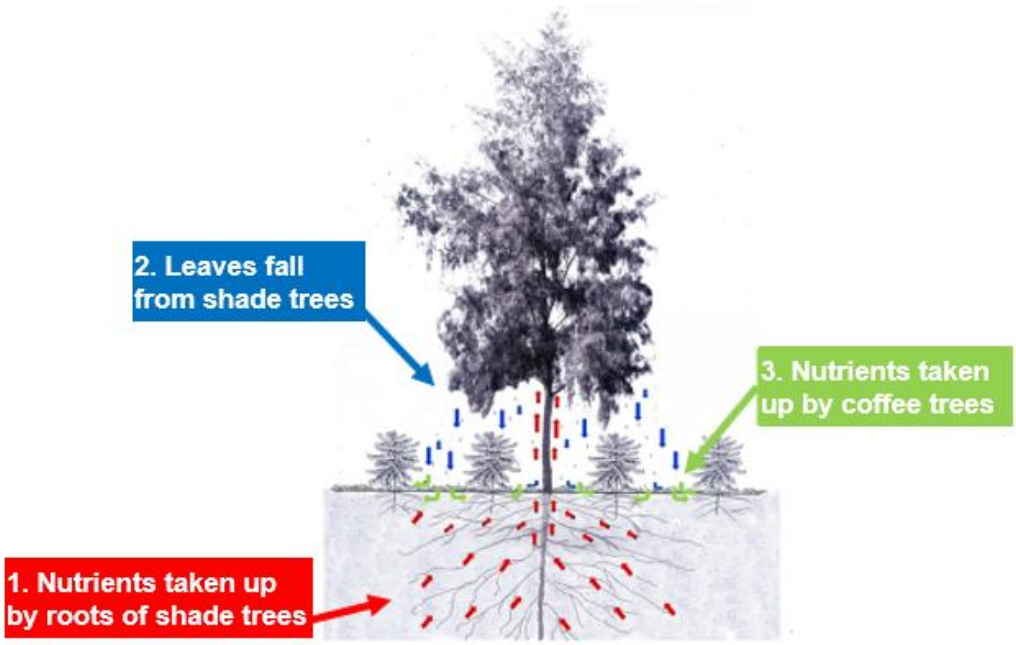

Figure 1. Recycling of nutrients by shade trees (Drawn by: Bob Kora, CIC)

Pests and diseases

Coffee trees grown under shade suffer less nutritional stress and are therefore more resilient to the impacts of pests and diseases (Schroth et al. 2000). Brown eye spot and coffee green scale are reduced by shade (Apety and Fumo 1998 cited in Brook et al. 2015). Coffee leaf rust (CLR) is enhanced by the presence of shade, however, the selection of shade tree can influence the persistence of the fungus. A good level of coffee tree nutrition and weed control, which can be supported by suitable shade trees, can reduce the incidence of CLR (Brown et al. 1995).

Coffee berry borer

Evidence suggests that shade trees amplify infestation levels of CBB as the pest is well adapted to a humid environment (Vega et al. 2015). Parasitoids, natural enemies of CBB, are negatively impacted by shade, however, the diversity and abundance of other natural enemies such as ants, birds and entomopathogenic fungi (e.g. *Beauveria bassiana*) are greater under shade (Escobar-Ramírez et al. 2019).

The practice most widely recommended for control of CBB is sanitation (Aristizábal et al. 2016), which is labour intensive. Fallen berries provide a refuge for CBB (Damon 2000) but are much easier to find when weeds have been suppressed by shade (De Silva and Tisdell 1990; Njoroge 1994). More importantly, the function of shade trees in synchronising coffee flowering would mean that labour allocated to sanitation for CBB control could be concentrated over a shorter period, making labour available at other times of the year for other livelihood activities.

Pollination

Good levels of pollination and fruit set can be achieved when shade is used as a tool to synchronise flowering (Boreux et al. 2013). The shade trees also provide habitat suitable for valuable pollinators (Roubik 2002).

3. Labour efficiency

Women assist in coffee production, primarily at harvest time. However, often they prioritise production of food crops (Inu 2015; Curry et al. 2019). Synchronisation of flowering means women could schedule labour-intensive food gardening activities to complement the coffee season. This would enable easier mobilisation of women's labour for coffee production during peak periods of labour demand.

Shade grown coffee provides two avenues for increasing labour efficiency:

1) Comparatively low inputs of labour to manage shade trees will suppress weeds and synchronise flowering (more efficient use of labour for weeding, harvesting and CBB control)
2) Synchronisation of flowering will result in higher pollination rates and fruit set and in turn lead to greater yields and returns to labour

4. Certification

If smallholders plan to become certified coffee growers, growing coffee under shade in combination with other improved management practices would be required for them to receive premium prices offered by most certifying organisations (Atallah et al. 2018).

5. Risk and resilience

Growing shade trees as part of coffee production systems has been identified as a mechanism to minimise risk (Gao 2018; Yunusa et al. 2020). Incomes over time are relatively stable as a result of consistent production, price premiums from certification and higher bean quality, and an income stream from the sale of timber (Gao 2018; Jezeer et al. 2018). Appropriately shaded coffee is also less susceptible to failing harvests (Nzeyimana 2018).

6. Climate change

From a broader perspective, growing shaded coffee in an agroforestry system is recognised as a practice that can be used as an adaptation strategy to mitigate the negative impacts of climate change. Enhancing biodiversity in coffee environments by incorporating a diversity of shade trees promotes resilience to fluctuating global markets, climate and weather (Lin 2007; Gidey 2020).

Research into shade trees and shade-grown coffee in PNG

Since the 1970s some valuable research on shade trees has been conducted in PNG by coffee and cocoa industry-based service agencies (Table 1). *Casuarina oligodon*, a tree species endemic to the highlands of PNG, has been used as a fallow species in subsistence food gardens for many centuries and has attracted much attention from local researchers (Bourke 1997). It provides many benefits to agricultural crops in the way of ecosystem services, particularly in nitrogen fixation and nutrient cycling, and is used widely as a shade tree in coffee. Different tree species, both introduced and indigenous, have been compared and assessed for their qualities as shade trees in coffee for controlling weeds, preventing soil erosion, enhancing soil nutrition and for supplementary uses such as timber for construction and fuel.

Table 1: A summary of some of the research conducted on shade tree species and the use of shade trees in coffee and cocoa production in PNG since 1975.

Reference	Investigation and findings
Parfitt 1976 (cited in Talopa 2003)	Assessed the effect of shifting cultivation on soils. Where Casuarina was used in food gardens, nitrogen levels increased with the age of the trees. With age came a more extensive root network and an increase in deep litter arising from leaf fall.
Thiagalingam and Fahmy 1981 (cited in Talopa 2003)	Compared N and C levels under different coffee shade trees (*Casuarina oligodon*, *Albizia stipulata and Crotalaria* spp.). Both elements were higher under *C. oligodon*.
Naug 1982	Examined the uses of *Leucaena* sp. in coffee production (as shade cover and in nutrition, erosion control, fuel and supplementary uses). Concluded that it was useful in all respects.
Byrne 1984 (cited in De Silva & Tisdell 1990)	Variation in total cost/ha for four years of weed control in two sites under varying shade conditions (none, Casuarina and Albizia) using four methods of weed control in coffee. Shade reduced the cost of weed control; Casuarina more so than Albizia.
Bourke 1984	Detailed the altitudinal range of coffee (Arabica and Robusta) and some associated shade crops.
Bourke 1985	Evaluated *C. oligodon* and its attributes in agroforestry. The system provides food from food crops, cash from coffee and some marketed food, and timber for construction and fuel, and postulates that returns to labour would be high.
De Silva & Tisdell 1990	Evaluated methods of weed control as a tool in management of CLR. Concluded that shade has a highly significant negative effect on weed control costs. Using shade reduces weeds and improves tree vigour and yields and should be incorporated into an integrated weed management program.
Harding 1994	Compared N in shaded and unshaded coffee systems and found that N was severely deficient in unfertilised, unshaded coffee, with small or no deficit in shaded, unfertilised coffee.
Bourke 1997	Investigated fallow species in light of increasing population density in order to understand why certain species are used including Casuarina in coffee. Emphasised the many benefits of growing *C. oligodon*.
Hartemink & Bourke 2000	Summarised research that had been conducted on nutrient deficiencies in PNG. Zn and N deficiencies had been reported in Arabica coffee grown under low shade.
Hombunaka & Harding 2001	Investigated the timing of fertiliser applications in coffee and found that heavily shaded smallholder coffee gardens are unlikely to respond to applications of inorganic fertiliser as there are sufficient nutrients present in the soil.
Hombunaka et al. 2002	Assessed the effect of rehabilitation, shade and fertiliser on smallholder Arabica coffee yield. Rehabilitation of coffee with medium and light shade can increase coffee production by more than two-fold, yet under heavy shade there may be no increase in yield.
Talopa 2003	Investigated the role of Casuarina in agroforestry systems including in coffee. As a shade tree in coffee, it reduces light which in turn reduces flowering and the incidence of overbearing dieback; it also fixes N.
Hosseini Bai et al. 2017	Studied the effect of shade-tree spacing and species on nutrient cycling in cocoa agroforestry systems. Shade tree spacing can influence organic matter input and plant nutrient uptake, with high density spacing resulting in soil organic matter depletion.
Curry et al. 2017	Assessed coffee management and farmer technical knowledge including in shade control. In most gardens shade management was basic. Less than half of the farmers knew when the best time was to apply shade control (or to prune shade) and very few understood the effect that shade tree pruning has on the major pests and diseases of coffee.

METHODS

The research findings presented in this article are from data gathered between 2010 and 2012 at four field sites in Eastern Highlands Province as part of an ACIAR project titled "Improving Livelihoods of Smallholder Families through Increased Productivity of Coffee-based Farming Systems in the Highlands of PNG'. The study sites were: Asaro, Bena, Baira and Marawaka (see Curry et al. 2017: 14-23 for a full description of methods). Asaro and Bena are within 20 km of the provincial capital of Goroka, and Baira and Marawaka are remote sites without road access. Data collection was carried out by research team members from CIC, NARI, CSIRO and Curtin University.

Quantitative data were collected during coffee garden inspections and when interviewing farmers. An inspection of each farmer's main coffee garden provided a snapshot of coffee garden standards and practices and identified the types and condition of shade trees. Farmers were interviewed to assess their level of technical knowledge of coffee garden maintenance and nutrient resource management. To determine the level of understanding of shade tree management, farmers were asked the best time to prune shade trees and coffee trees and the effect of shade tree pruning on existing pests and diseases.

RESULTS

Across all sites, coffee garden maintenance standards were 'adequate' for most gardens (Figure 2). This included maintenance or control of weeds, pests and diseases, shade, fencing, drainage, and standards of pruning, crop sanitation and nutrition. More specifically, for shade control, 45% of gardens had an adequate standard of shade control and 41% good shade control.

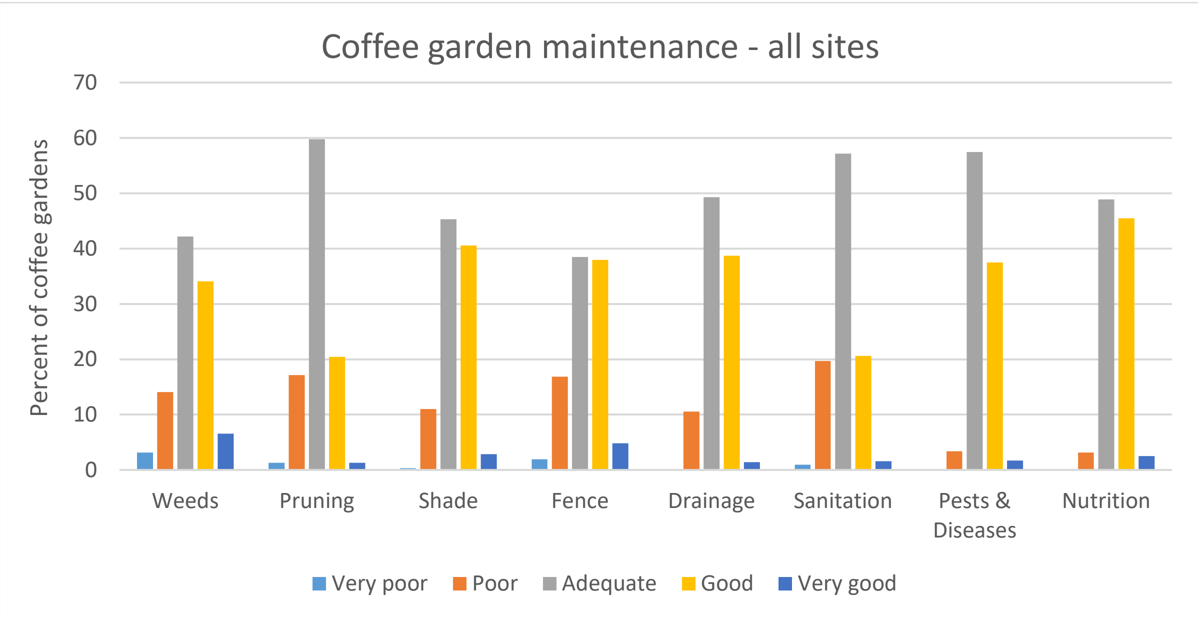

Figure 2. Standards of coffee garden maintenance

The most common shade trees present in coffee gardens were *Casuarina oligodon, Albizia* sp. and banana. Casuarina was present in 96% of gardens, and 43% of gardens had both Casuarina and Albizia.

Results from farmer interviews indicated that few farmers were aware of the most suitable time to prune shade trees to maximise productivity from their coffee trees (Figure 3). Shade trees should be pruned just prior to the coffee trees flowering to encourage synchronised flowering and maximise the number of flowers, and rates of pollination and fruit set. To keep the coffee trees healthy and productive the best time to prune them is immediately after the main harvest. Of the 281 farmers surveyed across all four sites, 95% knew that the best time to prune coffee trees was immediately after the main harvest. In contrast, just 36% of farmers knew the best time to prune shade trees (more than half thought, incorrectly, that the best time to prune shade trees was when coffee trees were pruned).

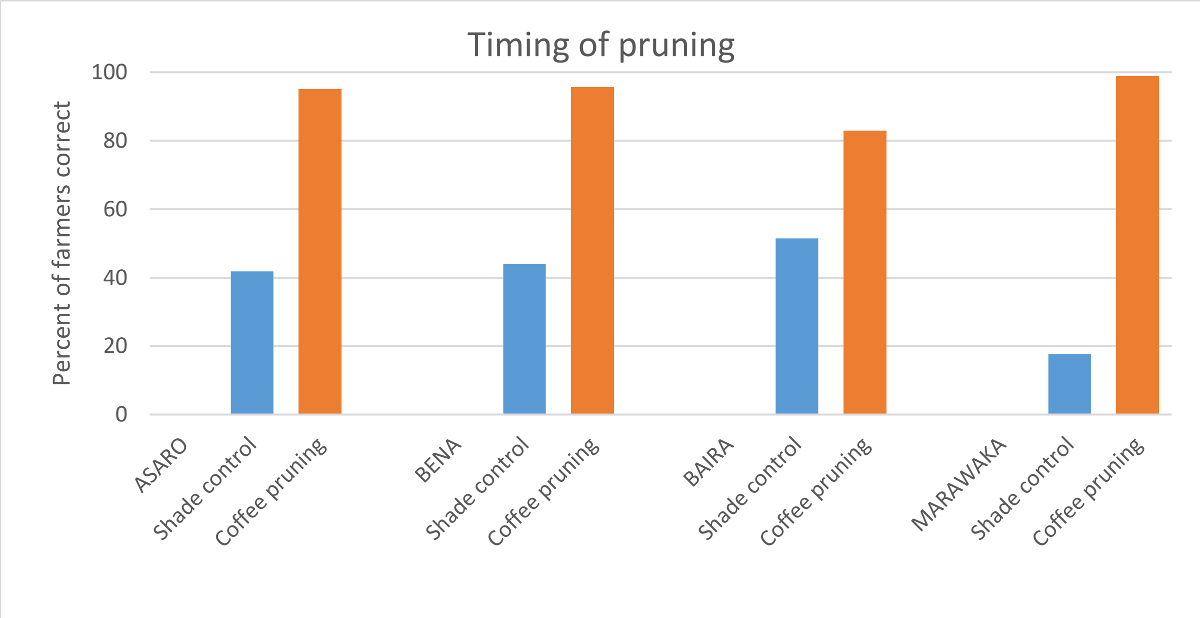

Figure 3. Percentage of farmers answering correctly for the optimum time to prune shade trees and coffee trees.

Coffee garden observations revealed that farmers tolerated relatively high crop losses due to pests and diseases. Pest and disease tolerance is typical of the low input system of smallholder production. Farmers were aware of the losses but had limited knowledge of appropriate control measures. If shade trees are pruned, thus reducing the level of shade, the incidence of green scale will increase but that of pink disease and CLR will decrease. Few farmers understood the effect of shade on the incidence of pests and diseases (Figure 4). With regard to green scale, 18% of farmers knew that pruning shade trees increased its incidence; 13% understood that it would decrease CLR; and 7% knew it would decrease the incidence of pink disease. Just 2 of the 281 farmers answered correctly for the effect of shade tree pruning on all three pests and diseases.

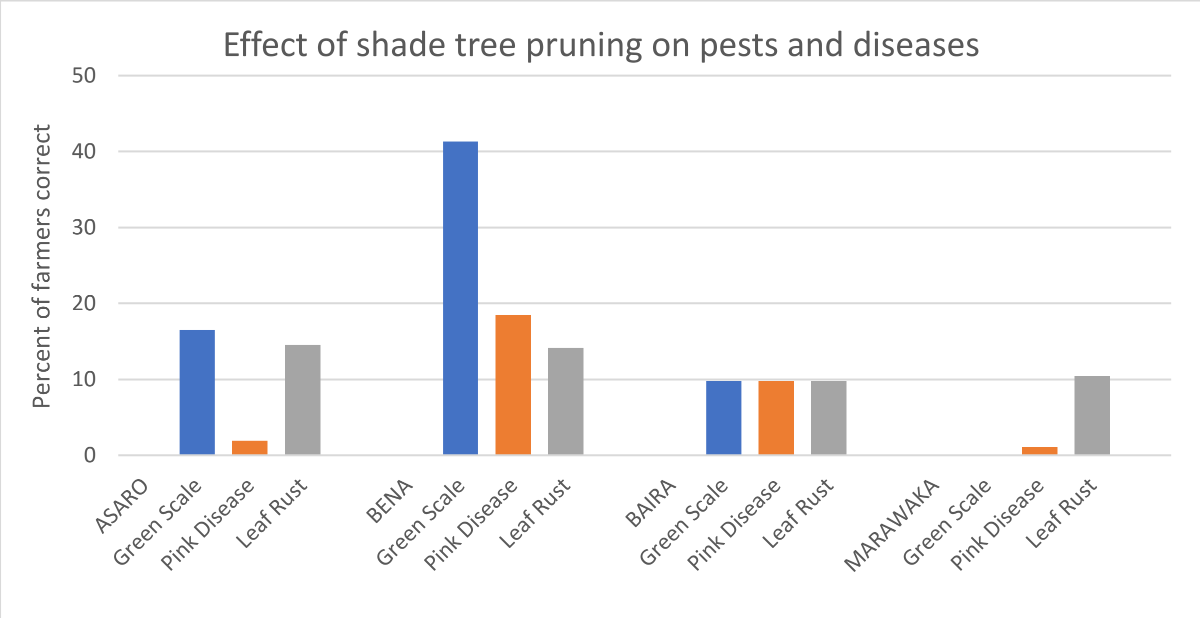

Figure 4. Percentage of farmers answering correctly for the effect of shade tree pruning on common coffee pests and diseases.

Growers reported receiving little or no coffee extension training. This helps to explain why farmers were not aware of the significance of shade trees in their coffee gardens and why they are poorly managed. The large knowledge gap on the effects of shade is a substantial barrier to improving production.

DISCUSSION

Despite extensive research on shaded coffee, few smallholders in PNG appreciate the economic and environmental benefits of appropriate shade levels in a low input system of production. Few are aware of how, with comparatively low inputs of labour, effectively managed shade trees can elevate the productivity of their coffee trees while also providing them with additional sources of income and a sustainable system of production. The current output of research on the use of shade trees in commercial coffee production should be of particular interest to those providing extension support and other resources to smallholder coffee growers.

Limited access to extension services has restricted the flow of new technologies and information to smallholders. In the government sector this has been due to poor governance and under-resourcing (Batt and Murray-Prior 2009; Uniquest 2013). Strong farmer-supply chain partnerships that existed during the plantation era are no longer present to provide extension support to farmers (Sengere 2016; Sengere et al. 2019).

Shade as a tool for pest and disease management has become more important with the arrival of CBB in the highlands. There is evidence suggesting that the presence of shade trees can result in higher infestations of CBB in some coffee gardens as described by Vega et al. (2015: 447). More recently, however, it has been reported that the capacity of the pest to reproduce is greater in unshaded coffee and although infestation rates are higher in shaded coffee, overall fruit damage is lower (Marino et al. 2016; Bagny Beilhe et al. 2020). The diversity and prevalence of many natural enemies of CBB are greater under shade than in unshaded coffee (Karp et al. 2013; Railsback and Johnson 2014; Aristizábal et al. 2016; Escobar-Ramírez et al. 2019; Moreira et al. 2019). With the incursion of CBB into the country, it will be problematic for the farmers to control it with limited or no knowledge of shade control.

CONCLUSIONS AND RECOMMENDATIONS

Coffee production, productivity and quality have been on the decline in PNG since the 1980s. Labour constraints are a major barrier to improving productivity and quality, yet few farmers are aware of the many strategies available to help increase labour efficiency and thus make coffee production a relatively more attractive livelihood option. Effective shade management is a tool that could be used to improve labour efficiency in weed, pest and disease control, and harvesting, while also improving coffee quality. This is becoming particularly important with the spread of CBB in the country. Furthermore, shade trees provide an alternative income source and provide ecosystem services that strengthen livelihood resilience in the face of climate change.

Improved and sustainable extension services are required to meet the needs of smallholder coffee farmers. Forging strong relationships with the commercial and public sectors, and farmers will be mandatory in achieving this goal.

The adoption of agroforestry principles for sustainable agriculture is a concept now taking off in many parts of the world under the mandate of the UN's 2030 Sustainable Development Goals, which aim to diversify livelihoods, improve food security and protect the natural environment. In some ways, PNG is already at the forefront of these ideas with agroforestry being practised in cocoa and coffee for many decades. There is an opportunity to build on this foundation to create a sustainable model of coffee production that generates both ecosystem services and enhanced economic opportunities for smallholders. Promoting effective shade management as a first step should be a priority for the industry.

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