

# THE PAPUA NEW GUINEA COFFEE HANDBOOK

(2nd Edition)

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COFFEE INDUSTRY CORPORATION  
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PAPUA NEW GUINEA



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The WORLD BANK



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## FOREWORD

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Coffee continues to provide the major source of cash income for a large proportion of the rural population living at altitudes of 1,000 masl and above and is increasing in importance at mid altitudes down to 700 masl. Coffee production had been stagnant and/or on a downward spiral with insignificant new plantings. Coffee farmers living close and or near to better road infrastructure are diversifying their income base to food production and marketing and in many instances uprooting coffee trees to facilitate production of vegetables. Also regrettably, in recent years the knowledge base of coffee farmers has fallen to a critical level due in part to the demise of the plantation and managed sector and ageing of the traditional smallholder growers, but more importantly, to the lack of a skilled and dedicated extension service. The lack of adequate financial support for the Research and Extension Division of the Coffee Industry Corporation combined with its inability to work in tandem with the Provincial Extension Divisions results in disjointed or no service to smallholder farmers. In the face of climate and rural social structure changes research and development agencies must be pro-active and responsive.

The Foreword to the PNG Coffee Handbook published in 1994 commented on the foresight of the Coffee Industry Board in establishing the Coffee Research Institute in 1986 and noted that “As a result of the hard work and dedication of the first intake of staff of that institution we now have a “formula” for successful coffee growing in PNG”. The 1994 Handbook was designed so that, as CRI generated new information, sections of the Handbook would be updated and revisions would be distributed to all purchasers of the Handbook and easily inserted. Unfortunately CRI lost sight of this commitment, therefore no revisions were prepared.

The team of experts convened to prepare this update corrected some minor inaccuracies identified in the 1994 edition, included new research information and drew on the experience of smallholder and commercial growers. It is being presented in the same binding format as the 1994 publication so as to enable updates to be inserted if any should be generated.

This PNG Coffee Handbook (2<sup>nd</sup> Edition) should be used as a reference document for Arabica coffee growers, coffee development planners and extension officers.

Technical information has been extracted for compilation of a Coffee Extension Manual for extension officers servicing Arabica coffee growers and for Extension Leaflets.

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## 1.0 INTRODUCTION

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In response to the decline in the coffee industry in the late 1980's and 1990's the Coffee Research Institute (CRI) developed a number of 'strategies' to address the fall-off and compiled The PNG Coffee Handbook with a view to providing coffee growers and processors with the latest technical information generated by its research activities. The Handbook was produced as a loose leaf booklet to facilitate ease of updating sections as and when new information became available. Regrettably, no updates were produced during the period from publication in 1994 to the present.

The Handbook (1994) noted that "replanting of non-productive coffee trees during the late 80's and 90's was slow at best, and in most cases non-existent; this in conjunction with lack of inputs resulted in severely run-down gardens, managed blocks and plantations." The situation has not improved since then, with gradual deterioration of smallholder gardens and the majority of managed blocks and plantations being abandoned. A 2014 study estimated that some 30% of all coffee has been abandoned and is now beyond the possibility of being rehabilitated. The need for a major replanting programme has never been greater.

With the aims of 'injecting new life' into agriculture and promoting the sector, the national government initiated and funded the National Agriculture Development Plan (NADP) in late 2006 with an amount of PGK38 million and increased to PGK100 million per year from 2007 onwards. Sadly, due to mismanagement the programme did not have the expected impact and was abandoned after some 5½ years. Government then directed its major investment in agriculture through the World Bank, International Fund for Agricultural Development and Government funded Productive Partnerships in Agriculture Project (PPAP), as a pilot project focussed on coffee and cocoa and confined initially to six provinces. As a result of initial successful implementation, PPAP has now been extended to all coffee and cocoa growing provinces.

PPAP plans to work with some 40,000 smallholder coffee farmers over the next 5 years, providing technical support and subsidised inputs to rehabilitate their coffee gardens, increase yield and improve quality. It is anticipated that the PPAP example will lead to a comprehensive replanting and rejuvenation programme for other smallholder coffee growers.

It is most important that the coffee garden rehabilitation programme be based on the best technical information available to the industry. To this end this publication draws together the latest research information and practical

experience to improve production efficiency, the key to economic viability of one of the country's most important rural industries. The replanting programme provides an opportunity to evaluate land suitability of existing and new garden sites prior to deciding on any new sites or replanting, followed by varietal selection, nursery establishment, land preparation, planting and post planting agronomic practices. All of these topics are detailed in the separate sections of this Handbook, together with post-harvest handling, processing and marketing.

It is to be hoped this Handbook becomes an essential reference source for all extension officers, planners and managers engaged in directing the rehabilitation of the coffee industry.

### **1.1 ACKNOWLEDGEMENTS**

A revision of a handbook of this scope could not have been accomplished without considerable effort by a number of technically competent individuals.

Each section was reviewed by a panel of professionals and experienced industry stakeholders, involving many hours of discussions, during which they contributed much valued expertise in all aspects of coffee husbandry.

The contributions made by the following are hereby acknowledged:

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## 1.2 NOTES FOR USERS

This Handbook is the **Arabica Coffee Handbook**, but knowledge of Robusta is included where appropriate.

This Handbook has been prepared in loose-leaf form so that regular amendments can be made, without having to carry out a complete reprint of all sections.

Each Handbook also carries a registration number so that we can keep a register of all Handbook owners. This is necessary in order that the CIC RGSD knows where to send up-dated sections. It is also essential that the Handbook owner informs the CRI of any change of address. Failure to do so will result in the owner not receiving up-dates and being unaware of new recommendations from the CRI.

Each page has a chapter number, followed by the page number within that particular chapter. In addition, every page has the year of publication printed in the bottom left hand corner. When the up-dated sections are received, the Handbook owner is advised to remove the earlier sections and replace them with the new ones. Do not keep replaced sections in the same folder as new ones, as unwary readers may use out-dated recommendations or banned chemicals.

No Handbook in any country has ever been written without at least some minor mistakes and it is unlikely that this one is unique in this respect. Should the reader find anything that needs correcting, or have any item that needs clarifying, please do not hesitate to contact the:

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## 2.0 THE COFFEE INDUSTRY IN PAPUA NEW GUINEA

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### 2.1 COFFEE INSTITUTIONS IN PAPUA NEW GUINEA

The early history of coffee growing in Papua New Guinea and its' regulation and management are detailed in the first edition of the Coffee Handbook and are not repeated here. The following description summarises the establishment of the first regulatory body in 1964 and subsequent changes, particularly those since 1986.

In July 1964 the Legislative Council established the **Coffee Marketing Board (CMB)**, with the passing of the *Papua New Guinea Coffee Marketing Board Ordinance, 1964*. A six man Board was appointed to take over all regulatory powers and functions of the coffee industry, thereby passing responsibility for policy determination to the Industry in consultation with the Department of Agriculture. The CMB licensed processors and exporters, established and managed a Stabilisation Fund and monitored exports.

After Independence, the **Coffee Industry Board (CIB)** was formed with the passing of the *Papua New Guinea Coffee Industry Board Act, 1976*. Members of the board were nominated by the various sectors of the industry: growers, processors and exporters with the chair appointed by government.

In 1983 CIB established a sub-committee, the **Coffee Research Committee (CRC)**, to coordinate investigations into die-back and the appointment of a senior international Plant Pathologist. It was quickly realised that the die-back was in fact 'overbearing die-back' resulting from removal of shade and failure to apply the necessary fertilisers. This marked the commencement producer funded research, through a levy collected at the point of export / sale.

The CRC recognised that government was incapable of managing the research necessary to support the industry as it moved forward and in March 1986 established the **Coffee Research Institute (CRI)** to undertake research into all aspects of coffee from land selection to export. The CRI engaged a Director and international scientists in the major disciplines, plant breeding, soils and plant nutrition, agronomy, pathology, entomology, spray technology, processing and information dissemination. The CRI programme was directed by a Coffee Research Advisory Committee (CRAC) with representatives for the industry, other research institutions, the university and government. Between 1985 and 1999 the CRC and CRI published some 87 Coffee Journals papers and 69 Coffee Research Reports. The current state of the CRI is described later.

The presence of Coffee Leaf Rust, discovered in Western Highlands in April 1986, caused major concern in the industry and focussed attention on the inability of provincial extension services to assist smallholders in dealing with the problem. Government responded with the establishment of the **Coffee Development Agency (CDA)** in 1987, intended as an industry funded coffee extension service. The CDA had its' own Board of Directors and a comprehensive complement of staff, numbering some 380 at its peak. Initially the CDA programme was supported by AusAID, both financially and technically.

The CIB was a shareholder in both the CRI and CDA and collected the producers levy on their behalf, since neither CRI nor CDA had statutory powers. Levies for CIB, CRI and CDA were clearly identified. As a result of the pro-active and cooperative approach taken by the CRI and CDA coffee production increased steadily from 860,000 bags in 1988 to 1.35 million bags in 1994,

It was perceived by some observers that having separate boards mitigated against integration of activities and collaboration between the three bodies. Accordingly, in 1989, at the request of government, UNDP engaged consultants to undertake a study of the organisation and management of the coffee industry in PNG. The report recommended that the three institutions, CIB, CRI and CDA, be amalgamated into a single body, with one board of directors to be known as the Coffee Industry Corporation. After widespread consultation the **Coffee Industry Corporation Limited (CIC)** was registered in 1991 under the Companies Act and the *Coffee Industry Corporation Statutory Powers & Functions Act, 1991* passed by parliament provided the legal basis to enable CIC to issue licenses, collect levies and regulate the industry.

Shares in CIC are held by Smallholder Associations (6), the Blockholders Association (1), the Plantation and Processor sector (1), the Exporters Council (1). and Government (3). Appointments are for 3 years, with each of the smallholders associations, blockholders, plantation/processors group and exporters council conducting elections to nominate their representatives. Government departments nominate their own appointees. The last Board's term expired on 1<sup>st</sup> December 2013. The Minister for Agriculture had the powers and obligation under the Regulatory Statutory Authorities Act 2004 to facilitate the appointment of new directors. This was not facilitated and for three (3) years to January 2016 there had been no fully constituted Board. Confidence within all sectors of the industry suffered as a result of the lack of representation and consultation. However in December 2015 the National Court ruled that a Board must be appointed by the end of February 2016

All administrative powers of the CIC are centred at its headquarters in Goroka. It was originally thought that having the CIC as a single unit to administer the coffee industry budget (levies plus government grant) would provide an opportunity for each section, Administration/Regulation, Research and Extension, to justify their claim for a share of the available funding. While this may have been the case the eventual allocation of the funds has been haphazard and strongly favoured administration/regulation. The result is that research and extension activities have been starved of funding for many years to the point of being almost dysfunctional.

## **2.2 MAJOR COFFEE GROWING AREAS**

Coffee is the major cash crop in the highland provinces of Papua New Guinea, with scattered areas in the high altitude zones of the nine mainland coastal provinces. To date no formal mapping of coffee growing areas in the country has been undertaken. Therefore, it is impossible to quantify the area under production either at a national or provincial scale. Consequently, the following estimates are derived from production statistics over the past several years.

The main Arabica coffee growing provinces, in descending order of importance are, Eastern Highlands, Jiwaka, Western Highlands, Morobe, Simbu, East Sepik, Southern Highlands, Enga, Madang, Oro, West Sepik, Milne Bay, Central and Gulf. Robusta coffee is grown in East Sepik, West Sepik, Madang, Morobe, Oro, Milne Bay, West New Britain and East New Britain.

Commercial scale production of Arabica coffee on plantations is confined to Western Highlands, Eastern Highlands, Jiwaka and Morobe. In general land selection for coffee production was not based on scientific principles but rather coffee gardens and estates were developed on whatever land became available. Baron Goto in 1956 commented that only one fourth of the area then under coffee could be considered as first class and one fourth was not suitable for coffee. Dr Brian Robinson remarked that in 1985 the majority of PNG's coffee was grown on sites deemed of low suitability. The result is low yields in both smallholder gardens and high inputs in large scale properties.

Harding, Bleeker and Freyne (1986) combined their knowledge of the complexity of the geology, soils, climate, landform and vegetation of PNG to develop a system of land evaluation for Arabica coffee production suited to this country. Applying this system to Western Highlands / Jiwaka suggests that considerable potential exists for expanded production on highly suitable

soils. Similar conditions are known to exist in other provinces but accessibility is a major constraint.

The potential for Robusta coffee in coastal provinces is extensive but competition from other tree crops, such as, cocoa, oil palm and coconuts, combined with lack of selection within the available planting material has restricted expansion. However, the CIC Research and Growers Services Division (RGSD) has undertaken varietal evaluation and selection of Robusta coffee at Omuru Research Station, near Madang. Omuru 1 is now the recommended variety.

## **2.3 INDUSTRY STRUCTURE**

The Industry is made up of growers, processors and exporters supported by the Coffee Industry Corporation Ltd., the structure and functions of which are described in the next section.

### **2.3.1 Growers**

Growers are divided into three categories depending on size of holding, namely, smallholders (less than 5ha), block-holders ( $\approx$  20ha) and plantations.

Of these, smallholders constitute the greatest number and account for some ninety five per cent of total production. It is estimated that there are around 524,400 smallholder growers, of which 496,892 grow coffee for cash (2011 Census). The remaining 27,508 reported that they grow coffee for their own use. Typically smallholders have less than 1,500 trees per household. They are distributed across all the coffee growing provinces listed above, producing parchment coffee for sale to processors or their agents. With very few exceptions smallholder coffee is grown under shade, thereby reducing the dependence on fertilisers or other purchased inputs, but imposing a ceiling on production potential. Generally, the smallholder allows his/her coffee to go into a sedentary stage during times of low prices and harvests only to meet requirements for cash.

The development of “20 hectare” blocks began in the 1980’s and gained momentum in the mid 1980’s. The block development consisted of customary land of approximately 20 ha with freehold title secured under the Land Tenure Conversion scheme and issued to a communal Business Group. The size and membership of the group depended on land equity or cash contributions, and it was typically supervised by management agencies. It was envisaged that the beneficiaries would provide the labour necessary to operate the property.

Then there are large plantations with an average area of 60 ha up to the largest one being 465 ha producing 1.5 to 2 tonnes per ha. Some of these plantations were formerly owned by foreign settlers. Many national groups who would otherwise be smallholders have taken them over. These changes commenced in the late 1970's and gained momentum through the 1980's resulting in almost complete handover to traditional owners and local entrepreneurs by 2000. The plantations were responsible for giving confidence to PNG nationals to venture into commercial production of coffee under block developments. At its peak there were over 150 plantations and some 600 '20ha' coffee projects. Today there are less than 15 plantations and few, if any, '20 ha' block projects functioning as commercial entities.

### **2.3.2 Coffee buyers and processors**

Smallholders are scattered over many areas where access is made difficult by the geographical conditions, poor or no road access, law and order problems, etc. Largely due to law and order problems and the problems associated with carrying cash into remote areas coffee buyers trading in parchment coffee are confined to the major towns and district centres, the exception being Western Highlands and Jiwaka, where coffee cherry is purchased on the roadside by factory representatives and/or traders. Coffee cherry is delivered to large wet factories, owned by plantations or stand alone factory units, and processed to parchment. This independent network of coffee buyers provides an essential link between the smallholder producers and the market outlets.

In 2015, 290 wet factories were licensed, 5 factories were denied a license, 17 factories operating in 2014 did not apply for renewal, and 9 factories were considered dormant having been unlicensed for more than 2 years. The up to date regulations relating to wet factory licensing conditions are available on the CIC website.

Dry mills are licensed by the Coffee Industry Corporation to monitor quality standards of green beans produced for export. There were 55 licensed mills processing green bean coffee in 2015, a further 4 mills were denied licenses and 12 mills were unlicensed since 2013. Up to date regulations are posted on the CIC website.

### **2.3.3 Coffee Exporters**

Trading in green bean was carried out by 21 licensed private exporters during 2015. The "Standing Conditions for Registration of Coffee Exporters: 1/2013" can be found on the CIC website. These conditions provide for five categories

of exporters, setting out the facilities which must be available, such as warehousing, machinery, etc., the lowest volume of coffee an exporter can export in a year (3,000 bags), and the scale of fees for each category.

Exporters negotiate prices with overseas buyers and arrange shipment in accordance with international trading practices. The Coffee Industry Corporation, although having powers to export, has delegated this function to the exporters. The CIC regulates and monitors the activities of exporters, in particular individual export contracts to ensure prices obtained reflect the international market and to ensure they maximise income on sale of PNG Coffee. All exporters are required to register contract details, including quantity, grade, price, price differentials, purchaser, destination etc. The CIC reserves the right to refuse a contract registration that is significantly lower than prevailing market prices

In 2015, without canvassing the view of the industry, the CIC introduced a new category of export licenses, known as “Reserved Export Licenses”. They were issued free of charge and without conditions to District Governments and other non-commercial agencies. None of the recipients have the necessary facilities; consequently there were no exports by this group during 2015.

Exports for 2015 totalled 42,800 tonnes valued at K393.5 million. (BPNG, pers. Com. May 2016)

#### **2.3.4 Coffee roasters / manufacturers**

Ten roasters / manufacturers were licensed in 2015, processing a total of 419 60kg bags GBE of which 193 60kg bags GBE was exported. This represents some .03% of total production. Table 2.1 shows the trend in exports since 2003

There is a growing trend towards roasting ‘speciality coffee’, with at least one exporter testing the European market with coffee capsules. In 2005 PNG made a considerable investment in export of roast but due to ‘shelf life’ issues this outlet was not sustainable. However, with improved packaging and transport exporting roasted coffee to adjacent markets, such as Australia, New Zealand, Korea and Japan, on a limited scale will improve returns to growers and traders.

## **2.4 PRODUCTION**

PNG produces both Arabica coffee (97%) and Robusta coffee (3%). Total production reached a record 1.488 million bags of 60 kg green bean in 2011



but has since dropped back to ≈735,000 bags in 2015. Production trends are shown in Table 2.2 to 2. 4

**Table 2.1 Exports of Roast and Ground Coffee, 2003 – 2015**

Year of Export	Volume (60kg Bags GBE)	FOB Value (PGK)	Price – (PGK/Kg)
2003	610	765,117	20.91
2004	804	927,563	19.24
2005	1,002	1,043,241	17.36
2006	820	867,635	17.64
2007	1,299	1,518,543	19.48
2008	839	997,736	19.83
2009	504	594,898	19.69
2010	378	534,765	23.61
2011	248	310,718	20.90
2012	301	333,813	18.50
2013	238	368,292	25.74
2014	132	181,904	22.89

**Table 2.2 Annual Coffee production - 60 kg bags of green bean, based on the coffee year October to September**

Coffee Year	Smallholder	Plantation	Blocks	Total
2010-2011	1,010,269	127,330	50m382	1,187,981
2011-2012	911,299	52,175	144,744	1,108,219
2012-2013	680,564	28,338	102,954	811,856
2013-2014	713,190	27,709	63,808	804,707
2014-2015*	714,736	6,831	34,874	756,440

**Table 2.3 Annual Coffee production - 60 kg bags of green bean, for 2010 - 2013 calendar years**

	Smallholder	Plantation	Blocks	Total
2010	751,393	94,702	37,472	883,567
2011	1,224,215	70,091	194,446	1,488,752
2012	677,714	28,219	102,523	808,456
2013	807,924	31,390	72,284	911,598
2014	741,623	7,088	36,186	784,896
2015*	653,503	19,570	61,908	734,980

\*Provisional data

**Table 2.4 Ten Year Trend in Coffee production - 60 kg bags green bean, based on the coffee year October to September**

Coffee Year	Smallholder	Plantation	Blocks	Total
1949/50			-	560
1959/60	13,000	30,000	-	43,000
1969/70	340,000	107,000	-	447,000
1979/80	612,000	289,000	-	901,000
1989/90	783,000	210,000	37,000	1,030,000
1999/00	1,092,000	200,000	40,000	1,332,000
2009/10	880,000	111,000	44,000	1,035,000

Repeatedly, CIC CEOs and Ministers for Agriculture have undertaken to increase production to 2 million bags per year; however, the production trend has been downwards instead of upwards. The decline in production is due in large part to the industry's lack of confidence in the CIC its' failure to consult with the various sectors and its inability to deliver competent technical advice to growers both small and large, processors and exporters. The CIC and its' agents have failed to communicate confidence in the future of a coffee industry based on the application of sound technical field practices, with careful harvesting and processing to produce a product to meet the demands of a changing world market.

As a result growers have failed to uproot and replant non-productive blocks of coffee, despite having access to newly introduced high yielding varieties and sound technical information supported by research results in The Coffee Handbook, 1994. The issue of producing top quality coffee of a consistent standard has not been explained properly to large sectors of the industry. Consequently, smallholders continue to produce a Y grade coffee which is highly sought after on the world market because it is of lower quality and lower price, but continue to 'complain' that either processors or exporters are 'ripping them off'.

All of the coffee industry institutions are justified and legally established but they are failing to deliver the expected outcomes. The inclination to restructure should be resisted; rather the current institutions should be managed better and focussed on results.

## **3.0 THE COFFEE TREE**

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### **3.1 MORPHOLOGY**

The coffee tree consists of one to several stems, whose extremity is a zone of permanent growth where nodes and internodes are forming. The stems develop only vertical internodes, the branches or primaries (Figure 3.1).

#### **3.1.1 The root system**

Until the root system of various cultivars of Arabica coffee, both tall and compact, are studied and documented under the growing conditions of PNG, the information provided below is tentative.

Roots of coffee can grow deeply, depending on the soil type and drainage. In most cases, 80% of roots occur in the top 30 cm. The root system can be modified by both cultural and soil conditions.

There are basically five types of roots which can be differentiated as follows:

##### **3.1.1.1 The tap root**

This is a stoutly built root which grows about 60 cm deep, and can develop into multiple units, which continue to grow as several separate tap roots. From this tap root originate two types of roots, axial and lateral.

##### **3.1.1.2 Axial roots**

There are between 4 and 8 of these roots, they grow vertically downward and can penetrate to 3m.

##### **3.1.1.3 Lateral roots**

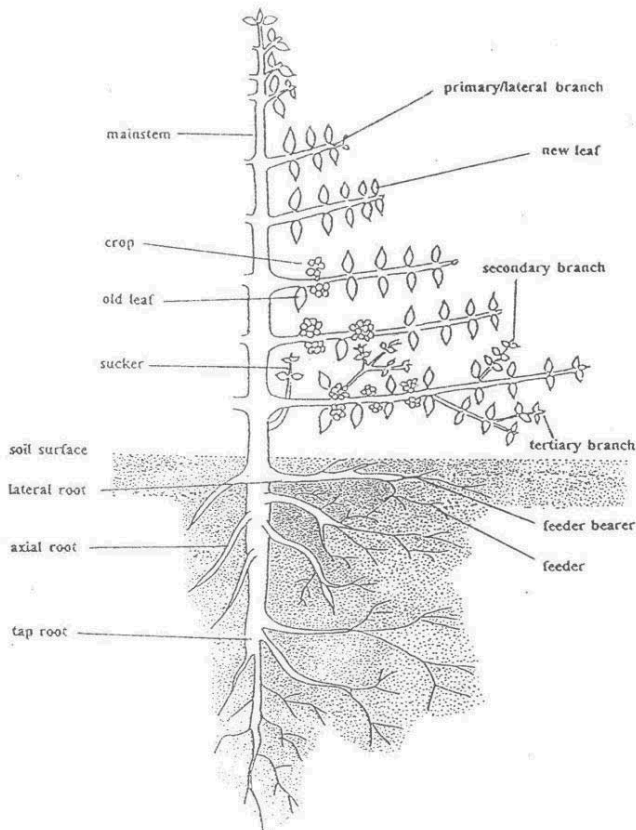
These are generally horizontal and occur in the top soil and occasionally at greater depths, when conditions can cause them to grow at an angle other than horizontal. They are sometimes known as “surface plate” lateral roots as they run more or less parallel to the soil surface at a distance of up to 1.8m from the trunk, depending on spacing. Some of the lateral roots growing at depth, form verticals and are hard to differentiate from axial roots.

##### **3.1.1.4 Feeder-bearers**

These are roots of varying length with even distribution which occur at about 25mm intervals on the tap, axial and lateral roots. Generally, they have a tendency to become shorter and more numerous near the soil surface.

### 3.1.1.5 Feeder roots

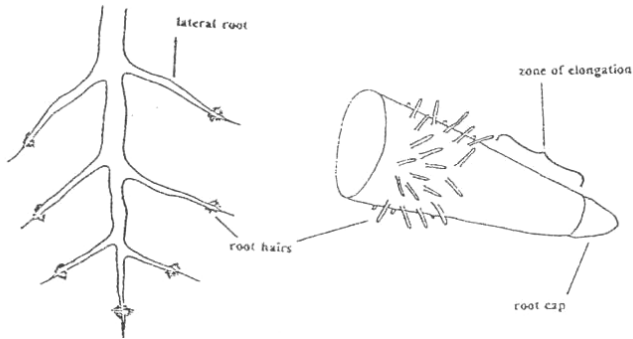
These are the roots arising from the feeder-bearers. Although they are more numerous near the soil surface, they can also be found at all depths.



**Figure 3.1: A young bearing coffee tree**

### 3.1.1.6 Root hairs

These provide the main absorbing region of the root. They are tiny, finger like outgrowths from the cells of the epidermis before it dies. They appear just above the zone of elongation, and there are none at the root tip or in the older regions of the root (Figure 3.2).



**Figure 3.2: Root hairs**

### **3.1.2 The shoot system**

#### **3.1.2.1 Stem and branches**

There is a vertical (orthotropic) main stem from which pairs of opposite leaves are subtended at each node. Each pair of leaves is oriented differently to the pair below. Located in the leaf axil of the main stem is a series of buds, a primary branch being formed from the top-most “head of series” bud. The lower buds can either remain dormant or produce orthotropic shoots (suckers), and occasionally, inflorescences. The buds at each node on the plagiotropic (primary or horizontal) branches provide the basis for inflorescences to develop. These buds can also develop into more plagiotropic branches (secondaries). They cannot, however, develop into orthotropic shoots.

#### **3.1.2.2 Leaves**

The leaves are normally arranged in a horizontal plane caused by the twisting of the branch and the leaf stalks.

The life span of leaves is variable (8-10 months) as it depends on the physiological state of the individual coffee trees. New leaf production usually compensates for the old leaf fall, and those which fall prematurely due to physiological dieback.

The mature leaves are elliptic to lanceolate, ribbed and waxy with varying size and colour according to variety. The size of leaves also varies according to age, location, season and shade.

### 3.1.2.3 Flowers

The development of a serial bud into an inflorescence comes about as a result of stimulation by plant hormones. When the buds are flat and triangular in shape, their future development may or may not be determined. When the buds appear thick and are enveloped in somewhat swollen rudimentary leaves (bracts) and covered with gum, they are florally determined. These buds grow until they are about 6mm long, when they enter a dormant phase; the future flowers are individually visible but still green. This dormant phase is usually broken by rainfall following a period of moisture stress. Blossoming usually occurs 10 days later, lasts for about 2 days, after which, the flowers wither.

Flowers are borne in the leaf axils on all forms of lateral branches. The number of inflorescences varies from 2-6 in each leaf axil, of 4-12 at each node. Usually an inflorescence consists of four flowers borne on short stalks attached to the main stem.

There are usually one or two main flowerings early in the rainy season, but a number of small subsidiary flowerings may occur. Under PNG conditions, these subsidiary flowerings after the main flowering between September and October are frequent. This is attributed largely to intermittent dry and rainy periods.

Arabica coffee is largely self-pollinated and the percentage of seeds resulting from natural cross-pollination is usually less than 10%.

An acute form of floral atrophy, termed “star” flowering, sometimes occurs, particularly at low elevation when the tree is under water stress or during periods of extended heavy rainfall. Star flowers are infertile and do not form fruit.

### 3.1.2.4 Fruit

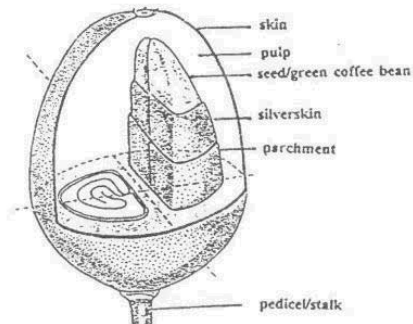
Fruit growth is not apparent for about 6 weeks after flowering (pin-head stage), and then the fruit swells rapidly over about the next 10 weeks. During the period of fruit growth, adequate moisture is required so that large seeds can be developed. Not all flowers will develop into fruit.

The crop development cycle can be summarised as follows, although in warmer climates the times will be shorter and in cooler climates they will be longer.

- Flowers open 1-5 weeks after the major stimulus – the beginning of wetter weather;
- Pinhead dormancy phase lasting 7 weeks;

- Period of rapid cherry expansion lasting 10 weeks;
- A 6 week period of endosperm formation, which begins in the middle of the period of rapid cherry expansion;
- Period of endosperm (bean) weight gain of 12 weeks;
- Final ripening stage of 6 weeks.

The time from flowering to maturing is about 8-11 months, depending on climate.



**Figure 3.3: Composite horizontal and vertical section of a coffee cherry**

The coffee fruit (Figure 3.3), which is commonly called cherry, is oval-elliptical, red in colour, with a short pedicel or stalk and a scar at the apex. The fruit normally contains two seeds which are flat on one side. When a single seed develops, it is oval in shape and is called a “peaberry”. The seed, which is the green coffee bean of commerce, is covered by a thin membrane (“silverskin”), which in turn is covered by an endocarp (“parchment”). The whole seed is covered by pulp (mesocarp), and skin (exocarp), which is removed by pulping/fermentation and washing.

### 3.2 ARABICA COFFEE VARIETIES

Arabica coffee is scientifically designated as *Coffea arabica* L. and originated in the highlands of Ethiopia. Several coffee varieties exist and they are known to have developed in one of the following ways:

- they arose spontaneously in nature (Typica, Bourbon) and their seeds were used for commercial growing;
- they are the fruit of selection work (Arusha, from Bourbon);
- they originate from mutants found by growers and propagated (Caturra, from Bourbon);
- they can be a result of mutation but are kept by scientists for genetic studies (Arusha with red leaves);

- they derive from a natural cross between two varieties (Mundo Novo = Bourbon x Typica) or even two species (Hibrido de Timor from a robusta x arabica cross);
- they derive by selection from a manmade cross (Catimor: selection from Caturra x Hibrido de Timor).

The main features of the commercial coffee varieties grown in PNG are given below. Seeds of these varieties are produced by the CIC RGSD. Some other varieties have been or are currently being tested but are not recommended for commercial growing until their performance has been tested under PNG conditions.

### **3.2.1 Blue Mountain *C arabica* var. *typica***

This is the first identified coffee variety grown in PNG. Its name “Blue Mountain” comes from Jamaica (West Indies) from where it was introduced and developed at Wau in the late 1920s. It was originally found in Yemen and is the earliest grown variety in the world. Its features are:

- bronze tips (young leaves);
- small and narrow leaves;
- horizontal branching;
- relatively small habit.

### **3.2.2 Bourbon**

It originates from East Africa but was developed from the island La Reunion (formerly Bourbon). It was introduced into PNG in the 1930s by the Lutheran Mission and developed in the Highlands together with Blue Mountain without formal selection. It has:

- green tips;
- erect branching;
- large leaves;
- relatively large size (tall and wide).

### **3.2.3 Arusha**

This is Bourbon type East African selection (from Tanganyika, drought resistant) introduced from Kenya in 1950. In trials at Aiyura it gave higher yields than Blue Mountain and Bourbon, with a fair bean quality. It is widely grown since its release corresponded to the main increase of coffee growing, in the 1960s. It differs from Bourbon by several features:



- bronze tips;
- broader leaves;
- larger beans;
- greater vigour and yields in PNG conditions.

#### **3.2.4 Caturra Red**

This is a natural dwarf mutant of Bourbon, found in Brazil, and first introduced from Trinidad (West Indies) to Aiyura in 1957. Its dwarf habit permits an outstanding productivity at high densities. It is best suited to high input conditions (plantations). It is characterized by:

- green tips (same as Bourbon);
- very short internodes resulting in compact shape;
- abundant ramification.

#### **3.2.5 Mundo Novo**

Selected in Brazil from a natural cross between Typica and Bourbon. An early selection was introduced from the USA to Aiyura in 1962, and found to be high yielding in trials. This strain can be described as follows:

- green tips;
- erect branching;
- not quite homogeneous in size but intermediate between Blue Mountain and Bourbon;
- relatively small beans.

All the above varieties are genetically fully susceptible to coffee leaf rust.

#### **3.2.6 Catimor**

Catimor is a derivative of Hibrido de Timor (HDT), a natural hybrid between *Coffea canephora* and *Coffea arabica*. HDT was used to introduce rust resistance into commercial coffee varieties. Catimor was introduced into Papua New Guinea in 1985, either directly from Portugal, or through Queensland, Australia. The seeds forwarded to Papua New Guinea were F6 generation. They were considered to be quite stable for rust resistance and other desirable traits. Catimor trees are characterized by:

- compact growth habit;
- resistance to coffee leaf rust;
- precocious nature, often coming to flowering in the first year of field planting;
- large dark green mature leaves;

- the tips are both bronze and green;
- good productivity and cup quality.

Catimor was evaluated under PNG conditions between 1987 and 1992 and three lines were recommended for commercial planting namely: PNI 082, PNI 083, PNI 085. The seeds from these lines are mixed in a 1:1:1 proportion and distributed to farmers as a composite variety.

### **3.3 ROBUSTA COFFEE VARIETIES**

The scientific name of Robusta coffee is *Coffea canephora*. Several populations of Robusta coffee are cultivated in the world.

#### **3.3.1 Besouki**

The Besouki strain grown in PNG was introduced in 1959. It is vigorous and produces large beans but is low yielding compared to other populations cultivated elsewhere.

#### **3.3.2 Omuru 1**

Omuru 1 is a composite clonal variety made up of three clones namely: PNI 191, PNI 194 and PNI 195. It has very small beans but is able to yield more than 2 tonnes per ha. It was introduced to PNG in 1994 and is now available from CIC RGSD.

## **4.0 COFFEE NURSERY MANAGEMENT**

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### **4.1 INTRODUCTION**

Coffee planting begins with good seeds and subsequently good coffee seedlings. It is therefore essential to obtain seeds from approved varieties and follow the recommended nursery practices to give the coffee trees a good start.

The production period of the coffee seedlings from germination to planting out in the field is approximately 6-9 months, during which time the seedlings acquire the desired morphological and physiological attributes to begin a new life in the field. The seedlings' growth rate depends on the prevailing climatic conditions and the standard of nursery management, therefore nursery operations should be started in time to ensure that the seedlings are ready for field planting at the beginning of the wet season.

Coffee seedlings are ready for field transplanting when they have 2-3 pairs of primary branches. This stage is reached after approximately 6 months but will depend on variety, prevailing climatic conditions and the standard of nursery management.

All nursery operations from seed germination should therefore be timed to ensure that the seedlings are ready for field planting at the appropriate time. Seedlings should not be allowed to become long and spindly while in the nursery.

### **4.2 SELECTION OF THE NURSERY SITE**

A good nursery site should be as close to the planting out area as possible, particularly if a bare root nursery is used, providing that the following requirements are met:

- On flat or gently sloping land;
- Near an adequate and permanent water supply;
- Away from hollows where cold air settles at night;
- The topsoil should be deep, friable with a high humus content and pH range of 5.0-6.0;
- Any site liable to waterlogging should be avoided;
- Avoid sites with large trees in the immediate vicinity;
- The site should be sheltered from the wind and protected from livestock by adequate fencing;

- The site should have good access by road to facilitate bringing-in the necessary nursery materials and distributing the seedlings to field sites for planting.

### 4.3 COFFEE SEEDS

Seeds of the recommended varieties can be obtained from the Coffee Industry Corporation RGSD at Aiyura, Eastern Highlands Province. The quantity of seed required can be estimated from the following information:

- There are approximately 4,500 seeds per kilogram, depending on variety;
- Under good nursery management, allowing for non-viable seeds and normal nursery culling, approximately 75% of the seeds will grow into plantable seedlings;
- The area (ha) to be planted at the preferred tree density.

**Example:** If you wish to plant 5 hectares at a density of 3,200 trees/ha, you will require the following seeds:

1 kg seed will provide  $4,500 \times 75/100 = 3,375$  viable seeds

5 ha at 3,200 trees/ha will require  $5 \times 3,200/3,375 = 4.75$  kg seed

Under uncontrolled conditions of temperature and moisture content, coffee seed should not be stored for more than three months. However, at 15°C and 20% moisture content seeds can be stored for a longer period. If seed is stored in airtight polythene bags at 15°C, and 20% moisture content, viability can be extended to over two years. However, to avoid any significant loss in viability and subsequent poor germination, it is advisable to germinate the seeds promptly.

### 4.4 GERMINATION BEDS

There are two types of seedbed for coffee seed germination, namely ordinary soilbed and sandbed. Whichever of these options is used, it is imperative to provide shade above all seedbeds or the young seedlings will die due to dehydration.

The shade frame can be made from any suitable wooden material, such as Casuarina (Yar) splits, approximately 1.5m high and 2m between posts, shade being provided by:

- pitpit (*Saccharum* sp.), kunai, banana leaves etc;
- bamboo splits;
- closely woven plastic netting (shade cloth).

The seedbed does not require nutrient application since nutrient reserves in the seed itself satisfy seedling requirements.

#### **4.4.1 Ordinary soilbed**

The soilbed should be constructed in an east-west direction for convenience of shading and should be about 1m wide and 10-12m long, with a pathway between each bed of 50-80cm.

The sides of the bed should be made of bamboo or split Casuarina about 15 cm high.

Soil from the pathways between the beds should be sieved to remove large stones and placed onto the beds. To improve the texture of the beds, sand or organic matter may be incorporated at this time.

##### Advantages

- It is cheaper;
- There is adequate retention of soil moisture.

##### Disadvantages

- There is a greater risk of exposing seedlings to soil-borne disease and pest attack;
- In areas where there are no suitable rivers, transport of river sand can be difficult and expensive;
- Rain splash can expose the young roots.

#### **4.4.2 Sandbed**

Germination of coffee seeds in sandbeds has given the best results in terms of speed of germination, percentage germination, elimination of deformed tap roots and ease of removal at the transplanting stage. The sandbed should be constructed with the same orientation and dimensions as the soilbed (see section 4.4.1).

The sides should be made of material suitable to support an 8-10cm depth of sand. Washed, sieved sand (a 4-6mm sieve is recommended) is then spread to a depth of 8-10cm.

##### Advantages

- Germination is faster;
- A high percentage of seeds germinate;
- Germination is uniform;

- Attack by soil-borne pests and diseases is minimised.

#### Disadvantages

- It is more expensive than the soilbed or bare root nursery;
- Regular watering is required due to the poor water holding capacity of sand;
- Rain splash can easily expose the roots.

### **4.5 SOWING SEED**

Whichever germination bed is used, seed should be treated and sown in the same manner:

- Before sowing the seeds, it is advisable to remove the parchment carefully by hand to improve germination;
- The seeds are soaked in water for about 12 hours to break dormancy and even out germination;
- The germination bed should be given a good watering;
- A groove 2cm deep is made across the bed and the seeds are sown with the flat side down, at a spacing of 2cm between seeds and 5cm between rows;
- The seeds are then covered with sieved sand or soil and a 2-3cm layer of grass is spread over the seedbed;
- The beds and grass should be lightly watered immediately after sowing.

Seed germination normally takes between 4-6 weeks, after which the grass covering should be carefully removed. However, a longer germination period may occur with different varieties, age of seed or non-husked seeds.

### **4.6 NURSERY TYPES**

Coffee nurseries can be categorised into those producing bare root seedlings or potted seedlings in polythene bags.

#### **4.6.1 Bare root nursery**

The advantages of this method are:

- It provides the cheapest method of producing coffee seedlings;
- The only inputs are the provision of shade and labour for maintenance;
- The seedlings are easy to transport since they are lifted from the ground by digging, and excess soil shaken free from the roots.

The disadvantages are:

- The roots are exposed on lifting and the seedlings must be transplanted in the field immediately to avoid drying;
- Normally, field establishment from bare root nurseries is less successful than from potted seedlings due to slower growth and more deaths due to greater transplanting shock;
- Soil from the bed should be used only once if possible to prevent a build-up of pests and diseases.

Bare root seedlings should be planted in the field at around 6 months.

#### 4.6.1.1 Bare root nursery bed preparation

All roots, stones and weeds should be removed, taking particular care to eradicate perennial weeds such as Kunai grass (*Imperata cylindrica*), couch (*Cynodon* sp.) and nut grass (*Cyperus* sp.). The beds should be marked and constructed in an east-west direction for the most effective shading and should be 1m wide and 10-12m long, with a pathway between each bed of 50-80cm.

Soil from the pathways should be placed on the nursery bed, which should then be cultivated by digging to a depth of at least 30cm. Soil alone can be used, particularly the first time, but it is better if sand, organic matter such as composted coffee skins, coffee hulls or manure is incorporated into the top 15cm at this time. Triple superphosphate at 25 g/m<sup>2</sup> or a suitable high P content compound fertilizer at 50 g/m<sup>2</sup> should be worked into the topsoil and a fine tilth produced.

The shade frame can be made from any suitable wooden material, such as Casuarina (Yar) splits, approximately 1.5m high and 2m between posts, shade being provided by pitpit (*Saccharum* sp.), kunai, banana leaves etc, or shade cloth.

#### 4.6.2 Polythene pots

The practice of raising seedlings in polythene pots is a common practice. It is essential to use perforated pots with an extra 2-3 holes at the bottom to avoid waterlogging and compaction of the soil.

The advantages of this method are:

- Ease of nursery management as seedlings can be sorted according to vigour;
- Seedlings can be transported over long distances without exposure or damage to roots, resulting in quicker and better coffee establishment;

- Planting can be delayed during unfavourable weather conditions without danger of losing the seedlings;
- Using the same soil year after year is avoided since new potting mixtures are prepared each season.

The disadvantages of this method are:

- The cost of polythene pots;
- Labour costs for filling and stacking polythene pots;
- The cost of transporting seedlings to the planting site;
- If sufficient top soil is not available locally, it will have to be brought in each year.

#### 4.6.2.1 Potting mixtures

A good potting mixture provides the best environment for root growth, resulting in overall better coffee seedlings. The proportions of the components of potting mixtures depends on the type of organic matter and fertiliser that are available.

##### Components

- a. Sieved topsoil  
To provide anchorage, a medium for root growth and supply of nutrients for the developing seedling.
- b. Sieved coarse river sand  
The addition of coarse sand increases the size of the air spaces and so improves drainage.
- c. Organic matter  
This provides a slow release of nutrients, improves water holding capacity and improves the physical texture of the potting mixture.

However, care should be taken over the source of organic matter used since animal wastes contain a higher concentration of nutrients. Chicken manure contains high levels of phosphate, hence, if chicken manure is used a smaller volume should be incorporated into the mixture, and triple superphosphate should be omitted from this particular potting mixture.



The following potting mixture has been found to be the most suitable:

<u>COMPONENT</u>	<u>AMOUNT</u>	<u>RATIO</u>
Sieved topsoil	300 litres	3
Sieved coarse river sand	200 litres	2
Coffee pulp*	100 litres	1
Triple superphosphate	250 grams	
Orthene**	140 grams	

\* 50 litres chicken manure can be used instead of 100 litres coffee pulp.

\*\* Or any other suitable pesticide, such as Karate.

The components should be thoroughly mixed before they are used.

#### 4.6.2.2 Polythene pots

The number of polythene pots that can be filled from each mix depends on their size:

<u>Size of polypot</u>	<u>Volume of one bag</u>	<u>Number filled</u>
30 x 20cm flat pack	3.0 litres	180-200
25 x 15cm flat pack	1.5 litres	360-400

It is preferable to plant out after 6 months, in which case the smaller pots should be used. These will be cheaper to buy, fill, and transport to the field, and will reduce the time of maintenance in the nursery. If the seedlings are to remain in the polythene pots for more than 6 months, the larger pots should be used to allow for adequate root development. Seedlings should not be kept in the nursery longer than 9 months.

### **4.7 TRANSPLANTING FROM GERMINATION SEED BED TO BARE ROOT NURSERY BEDS OR POLYTHENE POTS**

Coffee seedlings should be transplanted from the seedbed to the bare root nursery bed or polythene pots at the “butterfly” stage. They should never be left until the first true leaves appear. A planting stick 1cm diameter, 25cm long and tapering over the last 10cm, should be used to make holes for the seedlings.

#### **4.7.1 Transplanting into bare root nursery beds**

Before the seedlings are transplanted, the bed should be clean weeded and thoroughly watered. A hole, approximately 10cm deep, should be made with the planting stick, pushed in just far enough to accommodate the roots, avoiding air pockets and root bending. The tap root should be placed down

this hole, taking care that the tap root is kept as straight as possible and does not become kinked. Soil should then be firmed around the seedling.

Seedlings should not be pulled from the seedbed but should be lifted with the aid of a small stick. All self-sown seedlings, seedlings with deformed roots, or those with damaged growing points, should be rejected.

Seedlings should be planted 20-25cm apart, to accommodate the growing seedlings since they cannot be moved after transplanting.

#### **4.7.2 Transplanting into polythene pots**

The polythene pots, filled with the potting mixture, should be stacked in rows of 10 to facilitate maintenance operations and counting. The pots should be watered and a hole made with the planting stick in the centre of the pot. The young seedling is then inserted to the right depth and the potting mixture gently firmed around the roots.

#### **4.7.3 Precautions during transplanting**

- Seedlings from the germination beds should be placed in trays or small boxes and covered with a moist cloth or banana leaf to prevent wilting;
- Seedlings should be planted immediately and handled so that the tap roots are not damaged;
- Seedlings should be planted to the same level as in the seedbed.

#### **4.7.4 Direct planting of seeds into bare root or polypot nurseries**

Another option is to plant the seeds directly into the bare root nursery or the polypots.

The advantages of direct planting are:

- The time and effort of transplanting the seedlings at the butterfly stage are avoided;
- The need for seed germination beds is (largely) avoided.

The disadvantages of direct planting are:

- Not all seeds will germinate, and the failures will need infilling;
- Uneven germination and growth is likely.

#### 4.7.4.1 Direct planting into bare root nurseries

Seeds should be sown in accordance with Section 4.5, except that the seeds should be placed 20cm apart and 20cm between rows (to accommodate the growing seedlings).

At the same time, a small germination bed should be established and sown to provide the necessary infills. For every 4,000 seeds sown directly into the bare root nursery, 1m<sup>2</sup> of germination bed should be sown.

#### 4.7.4.2 Direct planting into polypots

The polythene pots are filled in the normal way with the potting mixture, and a single seed is sown in the centre of each pot.

At the same time, a small germination bed should be established and sown to provide the necessary infills. For every 4,000 seeds sown directly into the polypots, 1m<sup>2</sup> of germination bed should be sown.

### **4.8 NURSERY MAINTENANCE**

Nursery maintenance operations include watering, weeding, shade regulation, fertiliser application, disease and pest control, and in the case of polypot nurseries, spacing of polypots when seedlings are larger.

#### **4.8.1 Watering**

It is important to carry out regular and adequate watering of the seedlings to ensure that they survive in the germination beds and in the nursery. Initially, water should be applied 2-3 times a week, depending on the weather conditions. If foliar feeds are used, the frequency of watering can be reduced and care should be taken to avoid waterlogging.

#### **4.8.2 Weeding**

All weeds should be removed regularly, as necessary, by hand to avoid competition for moisture and nutrients.

#### **4.8.3 Shade regulation**

If seedlings are not hardened off gradually by careful and progressive shade removal, the transplanting shock and leaf damage from full exposure in the field will cause leaf loss and serious development delays, or even long term crop reduction.

Too much shade results in weak, thin stemmed seedlings with long internodes, whereas too little shade will require more nutrient application, more watering and could result in scorching.

During the last 2 weeks, preferably 4 weeks, before transplanting into the field, the seedlings should be completely unshaded. Also, during this final hardening-off period, watering should be reduced to a minimum.

#### 4.8.3.1 Timing of shade removal

If the seedlings are to be planted in the field at the end of 6 months in the nursery, the shade should be reduced by 30% for month 4 (when the coffee should have 4-5 pairs of leaves), reduced by a further 30% for month 5, and fully unshaded for month 6. A polypot nursery should use the small polypots for this planting schedule.

If the seedlings are to be planted in the field at the end of 9 months in the nursery, the shade should be reduced by 30% for months 4 and 5, reduced by a further 30% for months 6 and 7, and fully unshaded for months 8 and 9. A polypot nursery should use the larger polypots for this planting schedule.

#### 4.8.3.2 Shade material

Using bush materials to create the nursery shade is cheap and convenient, and they are easy to thin evenly. A degree of thinning will also occur naturally as the material dries and blows off. It is therefore the most practical material for small nurseries.

Shade cloth (plastic mesh) is more expensive, but it can be reused. It is however, difficult to thin evenly, since it has to be rolled back. Different density cloths could be used, but this would be even more expensive.

#### **4.8.4 Fertiliser application**

Where the correct nursery bed and potting mixtures have been used, there may be no need for additional fertiliser application. However, it is usually advisable to apply a complete foliar feed at monthly intervals, particularly where organic matter has not been used in the nursery bed or polypot mixture. The standard mix described in Table 7.6, containing a proprietary NPK product such as Folifert, Liquifert, Spreigrow, Bayfolan or Nitrophoska and a proprietary micronutrient product such as Fetrilon Combi 1 or 2, is most appropriate.

In cases where major nutrient deficiencies become apparent, an application of NPK at the appropriate rate per seedling may be applied.

Home-made foliar feeds are not recommended because they are rarely as effective as proprietary mixes, and any small savings achieved may prove to be false economies. If home-made foliar feeds are used, care should be taken to avoid biuret damage (from urea) since nursery seedlings are particularly susceptible.

Although this schedule should provide more than enough nutrients for the growth of healthy coffee seedlings, seedlings should be inspected regularly. If any signs of nutrient deficiency, particularly nitrogen, are observed, applications of the standard foliar feed should be increased to fortnightly for a two month period. As with all foliar applications, it is not recommended that fungicides or insecticides be mixed with foliar fertiliser.

#### **4.8.5 Disease and pest control**

A common disease in germination beds is “damping off”, caused by fungi such as *Rhizoctonia solani*, or other soil borne pathogens. The seedlings become discoloured and the hypocotyls (at ground level) are constricted. The affected seedlings die within a few days. The disease may be controlled by watering with a 0.5% copper solution.

Coffee leaf rust can also be controlled by application of 0.5% copper solution.

A disease encouraged by little or no shade is brown eye spot, *Cercospora coffeicola*. This disease may be controlled by 0.5% copper sprays at 4-6 weeks intervals.

Green and brown scales are common pests of coffee seedlings and may be controlled by spraying with 0.05% Malathion plus 0.25% wetting agent. A suitable mixture would be 10 ml Malathion 5.0% EC, plus 25ml wetting agent, in 1 litre of water. The treatment can be repeated every two weeks if necessary.

If cutworms continue to be a pest after the addition of insecticide (such as Othene dust) to the potting mixture (see Section 4.6.2) they may be controlled by further pesticide application.

#### **4.8.6 Spacing**

As the polypot seedlings grow and primaries begin to develop, self-shading will occur, normally at the 6-8 week stage. When this happens, polypots should be re-stacked at a wider spacing and the operation repeated as necessary, so that any contact between neighbouring seedlings is avoided.



## 5.0 FIELD ESTABLISHMENT

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### 5.1 SITE SELECTION

The wide range of physical environments found in Papua New Guinea vary greatly in their ability to support rain-fed Arabica coffee. The less suitable the physical environment, the more difficult and expensive it will be to grow Arabica coffee and the lower the yields that will be produced with a given set of inputs.

The need for correct site selection is brought into focus by increasing land shortages, the repayment commitment associated with development of loan-financed managed coffee, low coffee prices and the inputs necessary for adequate disease and pest control. Unnecessarily low yields or wastefully high inputs must be avoided wherever possible.

#### 5.1.1 Land attributes affecting site suitability

The seven land attributes which are most relevant in assessing site suitability for Arabica coffee production under PNG conditions are:

- Drainage/effective soil depth;
- Air temperature (altitude);
- Mean annual rainfall;
- Erosion hazard;
- Soil chemical fertility;
- Accessibility;
- Present land use.

##### 5.1.1.1 Drainage/effective soil depth

Drainage/effective soil depth is probably the most important of the attributes affecting site suitability for Arabica coffee production in PNG. Since coffee roots will not grow into waterlogged soil, the drainage/effective soil depth of a site determines the extent of root development.

The shallower a root system, the less effective it is in absorbing moisture or nutrients, and in providing a secure anchorage. In most situations, the drainage and effective soil depth can be quantified as the depth of free draining soil, as revealed in a soil pit or auger core. The upper limit of moderate or strong gleying (usually indicated by pale grey matrix colours or

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Note: All terms used in this section conform with the Food and Agriculture Organisation (FAO) terminology

large numbers of grey and/or red mottles) defines the depth of free-draining soil. However, it should be noted that very poorly drained soils with large amounts of organic material on the surface, such as peat, often have very dark grey or brown stained subsoils.

In some situations, the effective soil depth may be limited not by moderate or strong gleying, but by rock, ironpan, packed gravel layers, duripans or other indurated horizons. In such situations, the depth of free-draining soil cannot be increased by field drains. If however, the depth of free-draining soil can be increased by field drains, as with most imperfectly to poorly drained soils, the ease and practicality of draining the site should also be considered in assessing its suitability. The most important consideration in this regard is existence of suitable outlets for discharging the excess water, such as a stream, natural drainage channel, or simply lower land.

#### 5.1.1.2 Air temperature (altitude)

This is an important consideration because Arabica coffee is unable to tolerate frosts. Furthermore, low, but not freezing, temperatures lead to the production of more secondary and tertiary branches, and less apical dominance. Severely affected leaves are small, often distorted and may eventually fall.

High temperatures produce an excessively upright habit and above 25°C the photosynthetic rate is reduced. Above 30°C leaves begin to suffer damage. A constantly warm, humid climate induces excessive vegetative growth and the incidence of coffee leaf rust.

The optimum daily mean temperature is in the range 15-24°C.

Flowering, and hence cherry yields, are promoted by fluctuating day and night temperatures. A small diurnal temperature range results in the production of fewer flower buds and a greater proportion of abnormal, or “star”, flowers. However, too wide a range can lead to the condition known as “hot-and-cold”.

A strong relationship exists between air temperature and altitude. Air temperature declines with increasing altitude at a regular rate, this is known as the “lapse rate”. Generally, in PNG above 500 masl, mean annual minimum temperature decreases by 5.4°C per 1000m. However, broad valleys in the highlands are often warm for their altitude (eg. the Wau valley) and places with high rainfall tend to be cold for their altitude (eg. the Oksapmin Basin and the Mendi Valley).



Nevertheless, the temperature/altitude relationship is reliable enough for the more conveniently measured altitude to be used as a surrogate for air temperature, when assessing site suitability.

Particularly at high and low extremes of altitude, the presence of heavy shade moderates high diurnal temperature ranges by increasing very low night temperatures and reducing high day temperatures. This has the effect of reducing the yields of the coffee, but increases the chances of long term survival. This modifying effect of shade on the microclimate can be used to widen the range of physical environments suitable for Arabica coffee production, but at the expense of lower yields.

#### 5.1.1.3 Mean annual rainfall

In PNG, rainfall is the major determinant of water supply to the coffee, although many other factors such as temperature, cloud cover, shade, mulch and the soil's water holding capacity can also influence the supply.

Adequate supplies of water are required for photosynthesis, for the supply of plant nutrients, most of which are transported in solution, and for maintaining plant structure and turgidity. Too much rainfall, however, can be detrimental to coffee, due to an increase in fungal diseases, and flowering abnormalities.

The annual distribution of rainfall is as important as the total rainfall received. Flowering is induced by rain only if preceded by a period of water stress.

#### 5.1.1.4 Erosion hazard

The erosion hazard of a site should always be considered since erosion of the, often quite shallow, topsoil means the loss of most of the soil profile's available nutrients, organic matter, and often that part of the soil which is most able to hold readily available moisture. In several cases, the plants' anchorage may also be lost. If soil is lost, so will much of the applied fertiliser be lost.

In PNG, mass movements (landslides, slumps and mud-flows) are volumetrically probably the most important process of erosion. However, the less obvious, but usually continuous, processes of rainsplash and surface wash affect much greater areas. The risk of erosion by either of these processes increases with increasing slope, increasing rainfall erosivity, and increasing soil erodibility. By considering these three factors, an erosion hazard index for any particular site may be derived.

#### 5.1.1.5 Soil chemical fertility

The soil chemical fertility is obviously relevant in assessing a site's suitability, particularly with low-input management systems, which are largely dependent on the soil for the supply of plant nutrients. Many factors contribute to the soil's chemical fertility, including soil properties which affect the supply of various nutrients, their retention in available form, and toxicities.

In the PNG context, some of the most relevant soil properties contributing to the soil's chemical fertility are the soil's total nitrogen content, exchangeable potassium and magnesium levels, effective cation exchange capacity, P-retention and pH. These may be combined to produce a soil chemical fertility index.

#### 5.1.1.6 Accessibility

The accessibility of a site may be defined as the degree of difficulty in travelling to and from the site, to and from outlets for marketing the coffee and obtaining supplies such as tools and equipment, fertilisers and fungicides. It is a very difficult attribute to measure because many geographical and socio-economic factors are involved, and accessibility may not be constant over time. Nevertheless, it should always be considered when evaluating a potential site.

#### 5.1.1.7 Present land use

The present land use of a site affects the ease with which it can be cleared and prepared for planting coffee, and hence the cost of development. In the PNG context, the present land use is often dictated by socio-economic factors, particularly those relating to land ownership. A further socio-economic consideration is the value of the present land use that will be lost if the site is developed for coffee. Such problems are difficult to quantify, but clearly, the effects of the present land use on site development should always be considered when evaluating site suitability for Arabica coffee production.

### **5.1.2 The relevance of the management level at which coffee is produced**

The seven land attributes discussed in Section 5.1.1, when considered together, can provide an overall assessment of site suitability for Arabica coffee production. However, before site suitability for Arabica coffee production can be assessed, it is necessary to identify the coffee management level for which the site is being considered.

Section 2.3 describes three production sectors in the PNG Coffee Industry, namely smallholder (or village), block-holders and plantation (or estate) coffee production. For the purposes of site selection, these sectors may be summarised by two management levels namely “low input coffee production” (comprising smallholders), and “high input coffee production” (comprising blocks and plantations).

From section 2.3, it is clear that the low input coffee production system differs considerably from the high input system in almost all aspects of coffee management, and that the resources available in the two management systems are not comparable. Therefore, the two management systems usually respond in different ways to any environmental limitations to coffee production. Hence, different critical values for several of the attributes affecting site suitability are appropriate for the two management systems.

### **5.1.3 Critical values and suitability ratings for land attributes affecting site suitability**

The basis of assessing site suitability is a comparison of the requirements of the proposed land use with the attributes of the land. This is achieved by the use of conversion tables; one for each of the land attributes affecting site suitability, which relates the attribute to assumed levels of suitability (based on likely levels and costs of production).

Critical values are used to subdivide the total range of possible values for any particular land attribute into a finite number of divisions. Each division is allocated a suitability rating, designated R1, R2, R3 and R4, which decrease in suitability from R1 to R4.

This section therefore, considers in turn each of the seven land attributes affecting site suitability. Critical values are derived which enable any value to be allocated one of four suitability ratings, from R1 (most suitable) to R4 (least suitable). Where appropriate, separate critical values are derived for each of the coffee management systems.

#### **5.1.3.1 Drainage/effective soil depth**

Table 5.1 relates the three components of drainage/effective soil depth, namely depth of free draining soil, site drainability and effective soil depth, to the four suitability ratings and the two management levels. Critical values have been derived which are appropriate to the conditions found in PNG. A minimum effective soil depth of 0.50m is considered necessary for a site to be considered suitable.

**Table 5.1: Drainage/effective soil depth suitability ratings and critical values**

SUITABILITY RATING	DEPTH OF FREE DRAINING SOIL <sup>1</sup> (m)	SITE DRAINABILITY	EFFECTIVE SOIL DEPTH (m)	MANAGEMENT LEVEL
R1	> 1.20	Not relevant because no drainage is necessary	> 1.20	High and low input
R2	0.50-1.20	Not relevant because only shallow surface drains <sup>2</sup> are necessary	≥ 0.50	High and low input
R3	0.20-0.49	Frequent drains <sup>3</sup> are necessary to a depth of 1m. Suitable outlets exist. Mole drains or deep ploughing are not necessary	< 0.50 but after draining > 0.50	High and low input
		Frequent drains are necessary to a depth of 1m. Suitable outlets exist. Mole drains or deep ploughing are necessary	< 0.50 but after draining > 0.50	High input only
R4	0.20-0.49	Frequent drains are necessary to a depth of 1m but no suitable outlets exist.	< 0.50	High and low input
		Frequent drains are necessary to a depth of 1m. Suitable outlets exist. Mole drains or deep ploughing are necessary	< 0.50	High input only
	< 0.50 over rock	Not relevant because effective soil depth is inadequate	< 0.50	High and low input
	< 0.20	Not relevant because too wet to drain	< 0.20	High and low input

- Notes: 1. Values refer to the soil condition at the end of the wettest time of year.  
 2. Shallow surface drains are typically 0.30-0.50m deep.  
 3. Frequent drains are typically 5-10m apart.

Suitability ratings R1 and R2 can be derived simply from depth of free draining soil, since site drainability and the effective soil depth must automatically present no constraints if such depths of free draining soil exist. Sites with

suitability rating R3 contain inadequate depths of free draining soil, but with appropriate drainage inputs, can be rendered suitable. Those sites requiring high drainage inputs, (such as mole drains or deep ploughing to break-up indurated layers) are only suitable for use by the high input management system. Sites with suitability rating R4 are not considered suitable for Arabica coffee production since the depth of free draining soil is inadequate and for various reasons, cannot be increased to 0.50m.

#### 5.1.3.2 Altitude (air temperature)

Table 5.2 relates altitude to suitability ratings, for the two management systems.

**Table 5.2: Altitude suitability ratings and critical values**

SUITABILITY RATING	ALTITUDE RANGE (m.a.s.l.)	
	LOW INPUT SYSTEM	HIGH INPUT SYSTEM
R1	1300 – 1699	1300 – 1699
R2	1100 – 1299 1700 – 1899	1100 – 1299 1700 – 1899
R3	600 – 1099 1900 – 2500	1000 – 1099 1900 – 2000
R4	< 600 > 2500	< 1000 >2000

In terms of altitude, sites with suitability ratings R1 or R2 are the same for both the low input and high input management systems. Sites with a suitability rating of R3 however, are only marginally suitable, but for the low input system, wider altitude ranges are possible due to the possible modifying effects of heavy shade. It is assumed that for the high input system, the resulting lower yields would be unacceptable. Sites with suitability ratings of R4 are not suitable for Arabica coffee production.

#### 5.1.3.3 Mean annual rainfall

Table 5.3 relates mean annual rainfall to suitability rating.

**Table 5.3: Mean annual rainfall suitability ratings and critical values.**

SUITABILITY RATING	MEAN ANNUAL RAINFALL (mm)
R1 (and R2)	2000 – 2999
R3	1500 – 1999 3000 – 4000
R4	< 1500 > 4000

In terms of mean annual rainfall, there are no differences between the two management systems in site suitability ratings. Furthermore, only three suitability ratings are considered necessary. Sites with suitability rating R1 (and R2) are highly suitable for Arabica coffee production, it being assumed that the annual distribution of rainfall is also suitable.

Sites with suitability rating R3 are marginally suitable, and sites with rating R4 are not suitable, due to insufficient soil moisture or an increased risk of fungal infections or unfavourable annual rainfall distribution patterns.

#### 5.1.3.4 Erosion hazard

The erosion hazard of a site is assessed by deriving an erosion hazard index, based on the rainfall erosivity, soil erodibility and slope steepness. Index points for each of these three components may be obtained from Table 5.4, and added together to give the site's erosion hazard index.

Thus, for example, a site with moderate erosivity (= 2 index points), moderate soil erodibility (= 3 index points), and a slope of 18% (= 2 index points), would have an erosion hazard index of  $2 + 3 + 2 = 7$ .

**Table 5.4: Critical values and index points of components of the erosion hazard**

COMPONENT AND UNITS	CRITICAL VALUES AND INDEX POINTS			
	1	2	3	4
Rainfall erosivity (erosivity class)	Low	Moderate	High	Very High
Soil erodibility (erodibility class)	Very Low	Low	Moderate	High
Slope steepness (%) (°)	0 – 15 (0 – 8)	16 – 30 (9 – 16)	31 – 60 (17 – 32)	> 60 (> 32)

A site with a low anticipated soil erosion loss will have a low erosion hazard index (lowest possible = 3), and a site with a high anticipated soil erosion loss will have a high erosion hazard index (highest possible = 12).

Most of the Arabica coffee growing areas of PNG have moderate rainfall erosivities. The Star Mountains, most of Gulf Province, and much of the Sepik catchment area have high or very high erosivities. There is anecdotal evidence that PNG is experiencing an increase in high rainfall events, generally of short duration. It is reasonable, therefore, to assume moderate rainfall erosivity with high erosivity for short periods in all Arabica coffee growing areas.

The soil erodibility is the susceptibility or resistance of the soil to erosion. Many of the soils used for Arabica coffee production in PNG have low erodibilities. As a rough guide, soils with high organic matter contents, moderate to rapid permeabilities, moderate to strong structures and loamy textures, are likely to have very low to low erodibilities. Soils with low organic matter contents, slow permeability, weak structure, and sandy or heavy clay textures, are likely to have moderate to high erodibilities. Other clues may be obtained from field observations.

Evidence of gulleying, rill formation, and soil pedestals may indicate moderate to high erodibilities, whereas a deep, dark, well structured, friable topsoil may suggest very low to low erodibilities.

Table 5.5 relates the erosion hazard index points to suitability ratings for each of the two management systems.

**Table 5.5: Erosion hazard index suitability ratings**

SUITABILITY RATING	EROSION HAZARD INDEX POINTS	
	LOW INPUT SYSTEM	HIGH INPUT SYSTEM
R1	3 – 5	3 – 4
R2	6 – 8	5 – 7
R3	9 – 11	8 – 10
R4	12	11 – 12 or any land with slope > 60%

The lower the erosion hazard index, the higher is the suitability rating; that is, the more suitable is the site. In terms of the erosion hazard, a site is judged more severely for the high input system than for the low input system. This is because many of the management practices of the low input system (less frequent weeding, intercropping, clearing only small areas at a time) tend to reduce soil erosion losses, whereas many of the management practices of the high input system (regular clean weeding, no intercropping, clearing large blocks of land) tend to increase soil erosion losses.

Furthermore, there is a general reluctance by high input production systems to develop very steep land, due to the problems involved in bringing in and applying fertilisers, herbicides and fungicides, and harvesting and removing ripe cherries. Smallholders, with smaller inputs and outputs, are more able to grow coffee on steep slopes. It will be noted that any land steeper than 60% (32°) is considered unsuitable for the high input system.

### 5.1.3.5 Soil chemical fertility

The soil chemical fertility of a site is assessed by deriving a soil chemical fertility index, based on the soil chemical properties listed in Table 5.6. With reference to the critical values for each of the six soil chemical properties, index points are obtained for each property, and added together to give the site's soil chemical fertility index and hence its suitability rating (Table 5.7).

Thus, for example, a site with 0.30 g/kg total nitrogen (= 3 index points), 70 g/kg P retention (= 3 index points), 0.17 cmol/kg exchangeable K (= 2 index points), 0.80 cmol/kg exchangeable Mg (= 3 index points), ECEC of 9 cmol/kg (= 3 index points), and a pH in a 1:5 soil:water suspension of 5.6 (= 4 index points), would have a soil chemical fertility index of 3+3+2+3+3+4 = 18; and a suitability rating of R2 for both production systems (Table 5.7). A site with good chemical fertility attributes will therefore have a high soil chemical fertility index (highest possible = 24), and a high suitability rating; and a site with poor chemical fertility attributes will have a low soil chemical fertility index (lowest possible = 6), and a low suitability rating.

**Table 5.6: Soil chemical fertility index, critical values and index points**

CHEMICAL PROPERTY AND UNITS	ANALYTICAL METHOD <sup>(1)</sup>	CRITICAL VALUES AND INDEX POINTS			
		1	2	3	4
TOTAL N (%)	Kjeldahl	< 0.10	0.10 – 0.19	0.20 – 0.50	> 0.50
P RETENTION (%)	Blakemore, Searle & Daly	> 95	85 - 95	60 - 84	< 60
Exchangeable K (cmol/kg)	1N ammonium acetate at pH7	< 0.10	0.10 – 0.19	0.20 – 0.60	> 0.60
Exchangeable Mg (cmol/kg)	1N ammonium acetate at pH7	< 0.30	0.30 – 0.59	0.60 – 1.00	> 1.00
ECEC <sup>(2)</sup> (cmol/kg) or CEC (cmol/kg)	Exchangeable bases + KC1 extractable Al	< 2	2 - 5	6 - 10	> 10
	Exchangeable bases + exchangeable acidity	< 5	5 - 10	11 - 25	> 25
pH <sup>(3)</sup>	1:5 soil:water	< 4.5	4.5 – 4.9	5.0 – 5.4	5.5 –
		> 7.5	7.1 – 7.5	6.6 – 7.0	6.5

- Notes: 1. Details of analytical methods are included in Appendix 3.  
 2. ECEC to be used if possible, but if KCl extractable Al data are not available, CEC may be used.  
 3. For conversion of pH data obtained using a soil:water ratio of 1:2.5, add 0.3 pH units.



**Table 5.7: Soil chemical fertility index suitability ratings**

SUITABILITY RATING	CHEMICAL FERTILITY INDEX POINTS	
	Low Input System	High Input System <sup>1</sup>
R1	> 20	> 18
R2	15 – 20	13 – 18
R3	10 – 14	8 – 12
R4	< 10	< 8

Note: 1. Lower fertility indices are rated slightly higher for the high input system since it is assumed that fertilisers will be utilised to improve soil fertility.

#### 5.1.3.6 Accessibility and present land use

The constraints imposed by the accessibility and present land use of a site are very difficult to quantify, incorporating as they do a considerable socio-economic dimension. Thus, although critical values, and hence suitability ratings, for these two site attributes cannot be defined, a general assessment of the effects of accessibility and present land use should always be included when evaluating site suitability for Arabica coffee production.

The significance of constraints to development arising from site accessibility and present land use will differ depending on the management level being considered. For example, any site being developed for the high input system requires all year access by motor vehicles, whereas for the low input system such access is desirable but not essential.

#### 5.1.3.7 Summary of land attributes affecting site suitability, critical values and suitability ratings

For ease of reference, the critical values and suitability ratings for each of the five quantifiable land attributes affecting site suitability are summarised in Table 5.8.

**Table 5.8: Land attributes, critical values and suitability ratings for site suitability evaluation for Arabica coffee production in Papua New Guinea.**

LAND ATTRIBUTE AND UNITS	SUITABILITY RATING	MANAGEMENT SYSTEM AND CRITICAL VALUES	
		LOW INPUT SYSTEM	HIGH INPUT SYSTEM
DRAINAGE/EFFECTIVE SOIL DEPTH <sup>(1)</sup> (m free-draining soil)	R1	> 1.20	> 1.20
	R2	0.50 – 1.20	0.50 – 1.20
	R3	0.20 – 0.40 <sup>(1)</sup>	0.20 – 0.49 <sup>(1)</sup>
	R4	< 0.20 <sup>(1)</sup>	< 0.20 <sup>(1)</sup>
ALTITUDE <sup>(2)</sup> (m.a.s.l.)	R1	1300 – 1699	1300 – 1699
	R2	1100 – 1299	1100 – 1299
	R3	1700 – 1899	1700 – 1899
		600 – 1099	1000 – 1099
R4	1900 – 2500	1900 – 2000	
MEAN ANNUAL RAINFALL <sup>(3)</sup> (mm)	R1 (and R2)	2000 – 2999	2000 – 2999
	R3	1500 – 1999	1500 – 1999
	R4	3000 – 4000	3000 – 4000
		< 1500 >4000	< 1500 >4000
EROSION HAZARD (Index Points)	R1	3 – 5	3 – 4
	R2	6 – 8	5 – 7
	R3	9 – 11	8 – 10
	R4	12	11 – 12 <sup>(4)</sup>
CHEMICAL FERTILITY (Index Points)	R1	> 20	> 18
	R2	15 – 20	13 – 18
	R3	10 – 14	8 – 12
	R4	< 10	< 8

- Notes: 1. Refer also to Table 5.1 since depth of free draining soil is only one of three factors comprising “Drainage/effective soil depth”.  
 2. Altitude is used as surrogate for air temperature.  
 3. Only 3 suitability ratings are defined for mean annual rainfall.  
 4. Or any land with slope > 60%.

#### **5.1.4 The overall site suitability**

The previous Section 5.1.3 enables a suitability rating to be derived for each of the five quantifiable land attributes affecting the suitability of a site for Arabica coffee production, with due regard to the proposed management level of the development. This section explains how these five suitability ratings are considered together, to provide an overall site suitability, which is expressed as a single site suitability classification.

In order to combine the five individual suitability ratings, suitability points are substituted for each rating as listed in Table 5.9. It will be noted that because drainage/effective soil depth and altitude are considered to be the two most important land attributes affecting site suitability, the suitability points for these two attributes are weighted by factors of 3 and 2 respectively. Also, because the R4 suitability ratings for drainage/effective soil depth, altitude, rainfall and erosion hazard are each considered as “limiting” (i.e. they render the site unsuitable, regardless of the other suitability ratings), they are allocated zero suitability points.

**Table 5.9: Suitability points allocated for each suitability rating**

ATTRIBUTE	SUITABILITY RATING AND SUITABILITY POINTS			
	R1	R2	R3	R4
DRAINAGE/EFFECTIVE SOIL DEPTH	12	9	6	0
ALTITUDE	8	6	4	0
MEAN ANNUAL RAINFALL	4	N/A <sup>(1)</sup>	2	0
EROSION HAZARD	4	3	2	0
CHEMICAL FERTILITY	4	3	2	1

Note: 1. There are only three suitability ratings for mean annual rainfall.

The overall site suitability is determined by adding the five suitability points substituted for the five suitability ratings, and obtaining the site suitability classification from Table 5.10. Thus, for example, a site with suitability ratings of R3 (drainage/effective soil depth), R2 (altitude), R1 (rainfall), R2 (erosion hazard) and R3 (soil chemical fertility) would score  $6 + 6 + 4 + 3 + 2 = 21$  suitability points, and would therefore be classified at S3 (Marginally Suitable). A site with suitability ratings of R2 (drainage/effective soil depth), R4 (altitude), R1 (rainfall), R2 (erosion hazard) and R3 (soil chemical fertility) would be classified as N (Not Suitable) because of the limiting R4 rating for altitude.

The site suitability classification is expressed by three categories of decreasing generalisation, namely site suitability “Orders”, “Classes” and “Subclasses”.

Suitability Orders indicate whether the site is suitable or not. There are two site Suitability Orders, the Order “Suitable” (represented by the symbol “S”, and the Order “Not suitable” (represented by the symbol “N”).

Suitability Classes reflect the degree of suitability, and are numbered consecutively, by arabic numbers, in sequence of decreasing suitability. Three classes are recognised, namely “Highly Suitable” (S1), “Moderately Suitable” (S2) and “Marginally Suitable” (S3). There are no suitability classes within the Order “Not suitable”.

Suitability Subclasses reflect the kinds of constraints or limitations, such as poor drainage or erosion hazard, which are relevant to the particular site. They are indicated by lower case letters of mnemonic significance, such as **a** (altitude), **c** (accessibility), **d** (drainage/effective soil depth), **e** (erosion hazard), **f** (soil chemical fertility), **r** (mean annual rainfall) and **u** (present land use). It is recommended that drainage/effective soil depth and altitude limitations are indicated for any suitability rating other than R1, but that rainfall, erosion hazard and soil chemical fertility limitations are only indicated if the suitability ratings are R3 or R4. Accessibility and present land use limitations are also indicated, if they are considered significant. Thus, the overall site suitability is expressed as a single site suitability classification. For example, a site with an overall suitability classification of S2ae is Moderately Suitable, with limitations due to altitude and erosion hazard.

**Table 5.10: Converting suitability points into a site suitability classification**

SUITABILITY POINTS	ORDER	CLASS	SUBCLASS
> 27	S (Suitable)	S1 (Highly Suitable)	S1a, S1d, etc.
23 – 27		S2 (Moderately Suitable)	S2a, S2d, S2ae, etc.
17 – 22		S3 (Marginally Suitable)	S3a, S3d, S3ae etc.
< 17 or any suitability rating scoring zero	N (Not Suitable)	N (Not Suitable)	Na, Nd, Nae etc.

### 5.1.5 Final site selection

The final decision on site selection for Arabica coffee production must be made by the owners, managing agents, or funding agencies. However, the decision should be primarily based on systematic site suitability evaluation, such as that described above. Any site classified as N (Not Suitable) should not be developed for coffee production. Sites classified as S3 (Marginally Suitable) are not recommended for high input coffee production, particularly if loan-financed, although they may be acceptable for low input production. Sites which are S1 (Highly Suitable) or S2 (Moderately Suitable) are recommended for either high input or low input Arabica coffee production.

## 5.2 LAND CLEARANCE AND PREPARATION

### 5.2.1 Drainage

In Papua New Guinea, the provision of artificial drainage is generally an essential consideration when planting coffee. Coffee is sensitive to poorly drained soils and requires good drainage to maximise crop production. Most operations such as herbicide application, pruning and the picking of coffee, are mainly carried out manually, therefore the placement of drains may not cause much problem. When the grower is not sure how to develop a drainage system, he should seek advice from an expert to ensure that the following operations are carried out:

- Draining excess water and discharging it in a controlled manner;
- Preventing overflow onto low-lying land;
- Controlling runoff from steep land;
- Removing obstacles from encumbered land.

#### 5.2.1.1 Reconnaissance survey/mapping

A reconnaissance of the area is the first step in the planning stage. The object of the reconnaissance is to make oneself completely familiar with the area under consideration. All relevant observations and information should then be transferred to a map.

#### Points to be observed

- The general “lay of the land” including the direction and steepness of slope;
- Location of all natural watercourses. Even very small watercourses should be noted because they invariably indicate depressions and may give a good location for disposal drains, particularly with a view to discharge;
- Positions of hills and ridges will have a considerable effect on the layout of drains;
- Creeks or watercourses which cross the boundary from adjoining land should be noted, because they may become a source of flooding or may even disperse onto the block. In either case, cut off drains should be provided;
- Change in soil type. It is not always practical to locate and map every soil change, but it is important to note those soil features, particularly texture and topsoil depth, which will affect drain spacing, depth of cut and construction methods.

If available, aerial photos, in conjunction with a ground survey, are probably the best method of undertaking the reconnaissance survey.

The soils information is best gathered by using a hand auger, which should be capable of sampling to a depth of at least 1.5m as drains may be cut to this depth or more. If a hand auger is not available, small pits must be dug.

#### 5.2.1.2 Drainage requirement and layout

No two areas of land are the same and although it is possible to generalise on the subject of drain depth, spacing and channel size, it would be wrong to follow these generalisations without consideration being given to the individual features of the particular area concerned. The drainage requirements are largely governed by the following factors:

- Soil characteristics;
- Present drainage class;
- Size of the catchment area;
- Topography.

The drainage requirements can be satisfied by several different layouts, which will depend upon:

- Site development plans;
- Mechanisation availability.

#### Soil characteristics

The characteristics of soil, and in particular those which determine soil permeability (structure, texture, porosity, organic matter content), are the major factors in deciding the spacing and depth of drains (Table 5.11). Water movement through clay is very slow, with the result that the surface often becomes saturated during periods of wet weather. Under these conditions of slow permeability, effective drainage can only be obtained by using very closely spaced drains, in some cases as close as 3-5m, cut just below the clay zone. On the other hand, in rapidly permeable soils, drain spacings up to 50m or more would be sufficient.

**Table 5.11: Drain spacings for different soil types**

SOIL TYPE	DRAIN SPACING (m)
Clay	3-15
Loam	10-30
San	20-50 +

### Making drains

When draining an area which is later to be planted with coffee, it is important to carry out operations in the correct sequence.

The main drains should be marked and dug first, followed by marking the position of the coffee with sticks at the recommended spacing. Once this has been done, the field drains should be marked and cut in straight lines, between the rows of coffee markers, ensuring that they are not cut too near the markers. In order to reduce the risk of collapse, the sides of drains should be constructed at a slope of about 25 degrees from the vertical.

The planting holes should then be dug as recommended (see Section 5.2.5), and the coffee planted. Later, it may be necessary to modify the drains as required.

### Construction of a drain

With a line of pegs marking one side of the drain, the other side is measured to the required width. A rope pulled tight on both sides of the drain will ensure that the diggers cut a straight and uniform channel.

For draining large areas, a gang of workers with a supervisor should be allocated for digging, with all workers being allotted a task (work mark), so that a reasonable check can be maintained on labour output and costing.

Once the section has been prepared, construction can proceed with a minimum of supervision. Errors can be kept to a minimum if checks on depth of cut are made every 10-20m. The construction should always begin at the outlet end of the drain, so that the accumulated drainage water is discharged as the construction proceeds.

#### 5.2.1.3 Channel gradient (slope)

To a large extent, the slope of the channel governs the velocity of flow, and by careful siting of the main drains, it is possible to provide gradients which will give flow velocities within the required limits.

If the gradient is too steep, scouring and erosion of the channel will occur, whereas, if the gradient is too shallow, the channel will silt up and cause flooding.

**Table 5.12: Maximum permissible velocities (cm/sec)**

<b>MATERIAL</b>	<b>CLEAR WATER</b>	<b>WATER TRANSPORTING COLLOIDAL SILTS</b>
Fine sand	46	76
Sandy loam	53	76
Silty loam	61	91
Alluvial silt, non-colloidal	61	107
Ordinary firm loam	76	107
Volcanic ash	76	107
Stiff clay	114	152
Alluvial silt, colloidal	114	152
Fine gravel	76	152
Coarse gravel	122	183

From Table 5.12 it can be seen that soil type will determine the maximum permissible velocity of water in a channel, and hence the slope of the channel. A slope of 1:250 is considered safe for stiff clays, whereas for peats, a slope of 1:2,000 is more appropriate.

In plantations, where drains are generally longer, the slope of the channel should not exceed 1:400, but for smallholders, where drains are shorter, steeper slopes up to 1:25 are common and workable.

#### 5.2.1.4 Drain depth and width

The depth and spacing of drains are directly related, any change in one will affect the other. Depth and spacing of drains will depend on soil type and natural drainage status. A water table retained at 50cm from the surface will allow uninterrupted growth of coffee, so the spacing and depth should be such that the water table is retained at this level.

- **Depth.** Constant depth drains are easier to dig and maintain. Over deepening of the drain when silt is being removed can cause low spots which are difficult to remedy. The depth of drains should be such to give 50cm of well-drained soil between drains. This will mean drains of at least 50cm depth and up to 150cm depending on soil type.
- **Spacing.** On deep, well drained soils an occasional cut off drain may be required. On heavy clays, drains may be needed at 5m intervals, whereas for most soils, drains may be spaced between 15 and 20m.
- **Width.** The width of the drain must be sufficient to carry the volume of water which is governed by catchment area, drain length and maximum rainfall.



#### 5.2.1.5 Drain maintenance

In order to gain full, long term benefit from any drainage system, regular maintenance is essential. In clay soils, slumping of the sides of the drain is a common problem, which in smallholder gardens can be controlled by bamboo or timber retaining walls. Cutting, but not removal, of the grass along the sides and bottom of the channel together with the removal of accumulated silt and grass cuttings, should be part of normal drain maintenance. The base of the drain should be cleaned so that the original gradient and depth are maintained.

Drain outlets should be fenced with coffee sticks or other suitable material to prevent pigs from entering and digging up the drain sides.

#### 5.2.1.6 Special structures

On larger coffee developments, special drainage structures may be necessary and justified:

- Where drains are located at steeper gradients than those recommended, there are possibilities of serious soil erosion unless control measures are undertaken. The velocity of the water can be reduced by placing **stone-filled wire baskets (gabions)** across the base of the channel, and attaching them to the sides. These should be spaced so that the back-up water from one basket reaches the base of the next up-stream basket.
- It is unavoidable that on plantations some of the access roads will have to cross major drains. In order to overcome this problem, either a concrete or galvanised iron **culvert** and concrete retaining walls may have to be constructed.
- When installing culverts, they should be buried at least 1½ times their diameter below the surface, even if this means building up the road above the culvert. In peat soils, because allowance must be made for future deepening of drains, it is best to bury the culvert slightly below the surface of the base of the drain.
- Wherever possible, gully control should be achieved by vegetative methods or a combination of vegetation and cheap, simple structures. However, where an excessive sediment load threatens down-stream water supplies, a permanent **silt-trap** may have to be considered.

- The principle of a silt trap is to slow the flow of water sufficiently to allow sedimentation of the suspended particles. The requirements and design of silt-traps are the same as for water-storage dams, where the object is maximum storage capacity for minimum cost.

### **5.2.2 Commencing land clearance**

Just where the clearing of the land begins, depends primarily on the lay of the land. In cases where the land slopes to one side, the best place to start would be at the top of the slope working towards the lower end. In this case it would also be advisable to construct a storm drain before the clearing progresses too far, in order that it may catch the flood water likely to rush down during heavy showers from the slope above the area to be developed.

Where the land is fairly level or just marginally sloping, clearing can start at either end to suit the convenience of the farmer. In this situation most smallholders prefer to begin at the bottom of the slope and slash the vegetation working upslope.

#### **5.2.2.1 Method of clearing**

The time and work involved in clearing the land is governed by the type of vegetation and consequently the method employed.

In instances where the coffee development is to be carried out in a forest area, it would be worthwhile to make an assessment of the available timber and to selectively fell the useful trees first. Then, provided no shade is required, all the remaining trees may be felled; should shade be necessary, some of the forest trees could be employed for the purpose. Following felling of trees, care must be taken to ensure that the stumps and roots are removed completely; the remnant stumps and roots often become a source of root diseases such as *Armillaria* if they are allowed to decay on the site. Trees may be removed by either of the following methods:

- By poisoning the trees and stumps if time permits, since they die slowly;
- By uprooting the trees by means of a tackle and winch so that the roots are torn out of the ground, and the remaining root stumps pulled out with a tractor;
- Using a bulldozer or suitable tractor with chains for very large trees. The use of heavy machinery should be avoided as far as possible since they disturb the topsoil too much. It is often more suitable but also more economical to use hand labour and smaller implements.

Although the trees may be felled and the stumps removed over the entire plot, the herbaceous growth should be left as a soil cover for as long as possible.

The next step will be to clear the vegetation and unusable timber by burning in multiple fires rather than one big blaze so that the soil beneath is not harmed too much. Arabica coffee is extremely sensitive to high pH soils, therefore the timber should be stacked on the lines of the coffee inter-rows before being burnt, if possible.

The clearing of land which has only grass and/or pitpit, may be done by slashing as follows:

- Mechanically by means of a tractor and slasher, and the growth once slashed can be pulverised further into smaller pieces with a machine and then left there. This is later to be ploughed into the soil;
- Manually by using serifs and grass knives; if the slashings here are not going to be pulverised and ploughed into the ground, then they should be heaped and burnt in multiple fires.

#### 5.2.2.2 Land preparation for high input production system

Once the land has been cleared the next step is to prepare it for planting. Preparation usually begins with a round of ploughing and harrowing as this helps to destroy the roots of small plants, particularly the perennial varieties of grasses. The land should be dug or ploughed to a depth of between 25-30cm using a disc plough with a tractor and then left to dry for a week or so. Then if necessary, a second round of cultivation with a disc harrow can follow; this may have to be repeated several times to effect reasonable clearance. At the same time care must be taken to ensure that the soil is not broken up more than is absolutely necessary; it must be brought to a rough tilth stage.

While preparation is in progress a lookout must be kept for noxious weeds such as couch grass, since neither ploughing nor raking the creeping stems of this weed will suppress its vigour. These weeds must be controlled by using herbicides. It is always preferable to use herbicides before the coffee is planted rather than after, as you can quite easily damage the young trees in trying to get rid of the weed. Herbicide can however, be used safely between the rows without harming the coffee.

Having cleared, cultivated and cleaned the land, if there is to be a long period of almost a year or more before planting commences, then it is worth planting a good soil cover crop. This can later be ploughed into the ground as a green

manure before the marking of the block begins. Below are a few of the suitable cover crops:

<u>Technical name</u>	<u>Common name</u>
<i>Mucuna pruriens</i>	Velvet bean
<i>Pueraria hirsute</i>	Pueraria
<i>Calopogonium mucunoides</i>	Calopogonium

Where the ground cover is required for shorter periods one of the following may be used:

Cowpea  
Pigeon pea  
*Tephrosia* sp.

Cover crops may be hand sown or sown using a seeder. The cover crop chosen should preferably be a legume which is locally available and is known to grow well. This should reduce erosion during wet weather and suppress the germination of smaller weeds.

Roads should be lined and cut soon after the operation begins as these will help with access to the block by the machinery.

#### 5.2.2.3 Land Preparation for low input production system

Land preparation for the low input production system will depend on manual labour, perhaps with the use of some small-scale machinery such as chain saws. The coffee will require shade, so any suitable shade trees should be identified and retained. Other trees can be felled, chopped into smaller pieces and removed. As far as possible, stumps and roots should also be removed, or burned *in situ*.

Other vegetation should be slashed and/or pulled/dug up and burned; or herbicide may be applied to the slashed vegetation. If shade trees need to be planted, this should be done as soon as possible.

The cleared land may be utilised for food crops until the coffee is planted and established. Bananas, corn, legumes and other vegetables are suitable crops, although sweet potato should be avoided if possible since it can harbour pests of coffee.

#### 5.2.3 Spacing

The spacing at which coffee trees are planted depends on the growth habit of the cultivar (tall or compact), the pruning system to be adopted and whether

or not tractor access is required for spraying or cultivation. Other factors to be considered are slope, drainage and disease risk.

The tendency is towards closer planting because of much higher production levels during the early years. However, the benefits of close spacing tend to decline in later years unless appropriate pruning systems like rotational stumping are applied to mediate or eliminate the effect. Optimum coffee spacing should combine high plant populations with easy access for:

- weed control;
- fertiliser application;
- spraying for disease and pest control;
- maintenance pruning;
- harvesting the cherries.

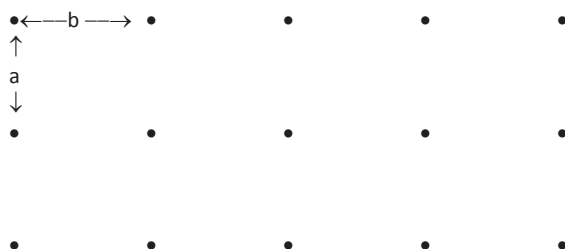
### 5.2.3.1 Spacing and land utilisation

The most frequently practised planting arrangements are square, and rectangular (hedgerow) spacings; triangular and avenue planting systems are also practised to some extent (See Figures 5.1-5.4).

#### **Square planting**

In the square planting system, the trees are spaced at equal distances in a grid pattern ( $a=b$ ), as shown in Figure 5.1.

The area per tree is determined by multiplying the distances in metres between trees, i.e.  $a \times b = ab \text{ m}^2$ , where  $a = b$ . Thus for a spacing of 1.95m x 1.95m, the area per tree is  $1.95 \times 1.95 = 3.80 \text{ m}^2$ .

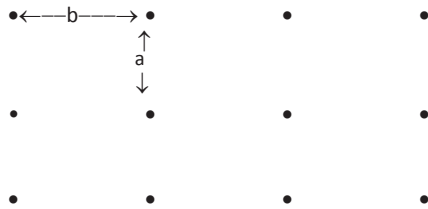


**Fig. 5.1: Square planting arrangement**

The tree population per hectare is determined by dividing the number of square metres in a hectare (10,000) by the area per tree. Thus, for a spacing of 1.95m by 1.95m, the area per tree =  $1.95 \times 1.95 = 3.80\text{m}^2$ , and the number of trees per hectare =  $10,000/3.80 = 2,631 \text{ trees/ha}$ .

### Rectangular planting (hedgerow)

The trees are spaced on a grid of unequal sides ( $a \neq b$ ) as shown in Figure 5.2.



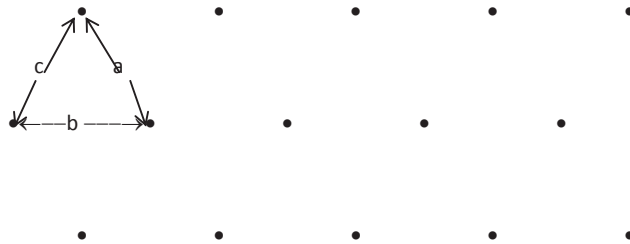
**Fig. 5.2: Rectangular planting arrangement**

The area per tree is determined by multiplying the distances between trees i.e.  $a \times b = ab \text{ m}^2$ , where  $a$  is not equal to  $b$ . Thus for a spacing of 2.5m by 1.5m the area per tree =  $2.5\text{m} \times 1.5\text{m} = 3.75\text{m}^2$ .

The tree population per hectare is thus  $10,000/3.75 = 2,667$  trees/ha

### Triangular planting

In triangular planting, the trees are spaced at the corners of an equilateral triangle, where  $a = b = c$ , as shown in Figure 5.5. In general, triangular planting gives about 10 to 15% more trees per unit area than square or rectangular planting.



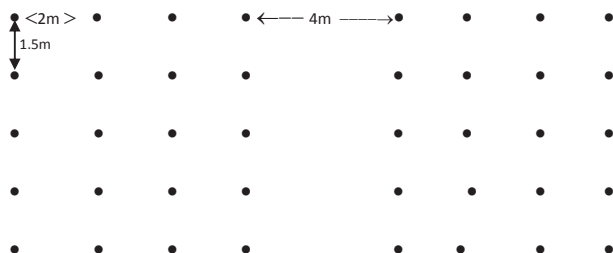
**Fig. 5.3: Triangular planting arrangement**

The area per tree is determined by multiplying two sides of the triangle by 0.87 (a constant for all equilateral triangles). Thus, for an equilateral triangle with 2.0m sides, the area per tree =  $2.0 \times 2.0 \times 0.87 = 3.48\text{m}^2$ .

The tree population per hectare is thus  $10,000/3.48 = 2,873$  trees/ha.

## **Avenue Planting**

The avenue planting system consists of 2, 3, 4, or 5 closely spaced tree rows with a wide space between the blocks, as shown in Figure 5.4.



**Fig. 5.4: Avenue planting arrangement**

The area per tree is determined by multiplying the space between the trees (1.5m in the diagram) by the sum of the inter-rows (3x2m) and avenue (4m), divided by the number of rows per block (4).

Thus, for four-row blocks spaced at 1.5m between trees and 2.0m between rows, with 4.0m avenues:

$$\begin{aligned}
 \text{Area/tree} &= \frac{1.5 \times (2.0 + 2.0 + 2.0 + 4.0)}{4} \\
 &= 3.75\text{m}^2 \\
 \text{Trees/hectare} &= \frac{10,000\text{m}^2}{3.75\text{m}^2} = 2,667 \text{ trees/ha.}
 \end{aligned}$$

### 5.2.3.2 Practical tree densities

The optimum tree densities are normally quoted in the form of a range. The density range depends on climate, tree type (tall or compact) and the management requirements, such as disease control. In order to manage Coffee Leaf Rust in PNG, it is recommended that all Arabica tall varieties should be planted at 2,500 to 3,000 trees per hectare. The CIC RGSD recommends 2,667 trees/ha at a spacing of 2.50m x 1.50m. Tables 5.13 and 5.14 show the number of trees per hectare for various single row, and square or triangular systems with access avenues, respectively.

Dwarf Caturra may be planted at a higher density range of 3,000 to 4,500 trees/ha. Two popular Caturra densities being practised are 3,030 and 4,444 trees/ha. The former density can be raised on two bearing heads per tree,

while the latter can only be raised on a single-stem on each tree. The respective spacings are 2.20m x 1.50m and 1.50m x 1.50m.

Dwarf Catimor may be planted at higher densities between 5,000 to 6,500 trees/ha, with a single upright on each tree. Suitable spacings are 2.0m x 0.9m (5,555 trees/ha), 1.3m x 1.3m (5,917 trees/ha), and 2.0m x 0.8m (6,250 trees/ha).

**Table 5.13: Trees per hectare for various single row spacing**

Spacing (m)	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
1.00	10000	8000	6667	5714	5000	4444	4000	3636	3333
1.10	9090	7273	6060	5195	4545	4040	3636	3306	3030
1.20	8333	6667	5555	4762	4167	3703	3333	3030	2778
1.30	7692	6154	5128	4395	3846	3418	3076	2797	2564
1.40	7143	5714	4762	4082	3571	3174	2857	2597	2381
1.50	6667	5333	4444	3809	3333	2962	2667	2424	2222
1.60	6250	5000	4167	3571	3125	2777	2500	2272	2083
1.70	5882	4706	3922	3361	2941	2614	2353	2139	1961
1.80	5556	4444	3704	3175	2778	2469	2222	2020	1852
1.90	5263	4210	3509	3007	2632	2339	2105	1914	1754
2.00	5000	4000	3333	2857	2500	2222	2000	1818	1667
2.10	4762	3809	3175	2721	2381	2116	1905	1732	1587
2.20	4545	3636	3030	2597	2273	2020	1818	1653	1515
2.30	4348	3478	2899	2484	2174	1932	1739	1591	1449
2.40	4167	3333	2778	2380	2083	1851	1667	1515	1389
2.50	4000	3200	2667	2285	2000	1777	1600	1455	1333
2.60	3846	3077	2564	2197	1923	1709	1538	1398	1282
2.70	3704	2963	2469	2105	1852	1646	1481	1347	1235
2.80	3571	2857	2380	2040	1786	1587	1429	1299	1190
2.90	3448	2758	2299	1970	1724	1532	1379	1254	1149
3.00	3333	2667	2222	1904	1667	1481	1333	1212	1111



**Table 5.14: Trees per hectare for various spacings in square and triangular planting systems with access avenues between blocks**

Between-row Spacing (m)	Within-row Spacing (m)	No. of rows per block	Access Avenue in Metres			
			Square Planting		Triangular Planting	
			3.00	4.00	3.00	4.00
1.00	1.00	2	5000	4000	5750	4600
		3	6000	5000	6900	5750
		4	6667	5714	7667	6571
		5	7143	6250	8214	7187
1.40	1.40	2	3247	2645	3734	3042
		3	3694	3151	4249	3634
		4	3968	3484	4563	3007
		5	4153	3720	4776	4278
1.80	1.80	2	2315	1915	2662	2203
		3	2525	2193	2904	2522
		4	2645	2364	3042	2719
		5	2723	2480	2132	2852
2.00	2.00	2	2000	1667	2300	1917
		3	2143	1875	2464	2159
		4	2222	2000	2555	2300
		5	2272	2083	2614	2996
2.50	2.50	2	1454	1231	1763	1415
		3	1500	1333	1725	1533
		4	1523	1391	1752	1599
		5	1538	1428	1769	1642

## 5.2.4 Planting holes

### 5.2.4.1 Digging

The size of the planting hole is very important for good growth of the coffee plants. A permanent crop like coffee must not be prevented from developing and establishing an effective root system.

The holes should be 45cm square and 45cm deep, approximately the size of a harvesting bucket. The top-soil and sub-soil should be piled separately, below the hole if the site is sloping.

The planting hole should be left open for a minimum of two weeks to allow for weathering to occur. However, where the soil has a poor physical and chemical status, the planting holes should be left open for about six (6) weeks after digging, for weathering to occur.

If the planting holes are seen to fill with water, then the site drainage is inadequate, and will need to be improved by deepening existing drains and/or by digging additional drains.

#### 5.2.4.2 Filling

When the sides of the planting holes have begun to weather, and at least two weeks before planting the coffee seedlings, the holes should be refilled with a mixture of approximately 4 parts topsoil to 1 part organic matter. The organic matter should ideally be compost, but any organic material, such as well rotted coffee skins will suffice. About 50gms of triple superphosphate (TSP) should also be added to the planting hole mixture.

If the topsoil is shallow, then it will be necessary to include some subsoil in the mixture for refilling the planting hole. In this case, the subsoil should be mixed with an equal amount of organic matter before being added to the mixture.

The organic matter and topsoil should be mixed thoroughly and the planting hole refilled such that a slight mound is formed above the ground. The remaining subsoil should be spread and levelled, and the planting hole marked with a stick.

After leaving the mound to settle for two weeks, planting can take place by opening a small hole and inserting the seedling (see Section 5.2.5).

### 5.2.5 Field planting

Planting should be done at the beginning of the main rains when the seedlings have 2 to 3 pairs of primary branches and have been in the nursery for 6-9 months. The younger the seedlings the greater the percentage field establishment, as long as sufficient brown bark has developed. This should occur as early as 6 months.

There are two important points to remember when planting:

- The seedling root mixture or the potting mixture should not be damaged or interfered with;
- The seedling must be planted in an upright position to the same depth as it grew in the nursery to avoid too deep or too shallow planting.

Planting procedure:

- The planting hole should be opened with a spade to receive the seedling;
- The plant should be held firmly in an upright position;
- In the case of polypot seedlings, the polythene pots should be slit open using a sharp knife and removed;
- The seedling should be placed in the centre of the hole. In the case of bare root seedlings, the tap root must be straight;
- The soil should be pressed firmly by hand as the hole is filled in. The soil should finally be compacted around the potting mixture and the surface mounded slightly to compensate for subsidence and to facilitate drainage.

#### Planting overgrown seedlings

If it is unavoidable that overgrown seedlings must be planted, then the following practices will improve field establishment:

- Bending  
The overgrown seedling may be planted in the normal way, then after allowing the roots to develop for 3 months, the stem should be bent over and pegged. When new suckers have developed, the old stem should be cut off.
- Root pruning  
Where the tap root has been bent in the polybag, it should be pruned at the point of bending and the seedling planted in the normal way.
- Capping in the nursery  
Overgrown seedlings may be capped 5cm above a pair of laterals which are between 30 and 45cm above the soil surface, providing that brown bark has developed at this point.

#### **5.2.6 Intercropping**

During the first two years of coffee establishment, smallholder growers should be encouraged to intercrop coffee with annual food crops.

The practice has five major advantages:

- Farmers are encouraged to maintain their coffee seedlings as they take care of the annual food crops;
- Mulching materials are provided from the crop residues;
- Erosion and weeding requirements are reduced;
- The farmers make use of relatively unproductive land by obtaining food crops while waiting for the coffee to yield returns in the third year;
- The farmers may generate income while waiting for the coffee to yield returns in the third year.

The most suitable crops for the purpose of intercropping are legumes e.g. peanuts and wing beans, because they add nitrogen to the soil. Other crops such as cabbage, broccoli, tomato and onion have been used in intercropping. Tall annual crops such as corn should never be planted in young coffee, as they compete with the young seedlings for light. The intercropping should be done within the inter-row avenues and not within 30 cm of the coffee trees.

Possible disadvantages of intercropping include:

- Pests and diseases of coffee may be encouraged. Sweet potato (kaukau) in particular should not be intercropped with coffee because sweet potato harbours pests of coffee;
- Cultivating inter-rows with annual crops may impede the development of the coffee's 'surface plate' lateral roots;
- The high nutritional demand of some crops may compete with the coffee for available nutrients.

### **5.3 MULCHING**

Immediately the coffee seedlings are planted in the field, they must be mulched, especially in dry areas. In wide spacing, a circle of dry grass, banana trash or corn residue should be put around the seedlings to a radius of 30cm. In rectangular (hedgerow) close spacing, a strip of mulch 60cm wide should be placed along the tree row. The mulch should never be placed right up to the stem of the plant. A space of 10cm should be left between the stem and the edge of the mulch to prevent rotting of the stem. The mulch is important to suppress weed growth around the young plants and to conserve soil moisture during the dry periods.

## **5.4 INFILLING**

Even under optimum management, some seedlings die during establishment, necessitating replacement if a uniform stand is to be achieved. Death of young seedlings is caused by various factors such as pests and diseases, wild animals, pigs, drought, injury during weed control, poor growth, poor planting, and poor seedlings. Infilling should be done at the earliest opportunity, and as often as necessary, to produce a uniform stand.

As much care should be taken with infilling as with the original planting. The remains of the original plant should be removed to prevent fungal infection of the infill.

## **5.5 REPLANTING**

### **5.5.1 Introduction**

A coffee plantation is expected to have an economic productive life of between 25 and 40 years. Thereafter, it is necessary/advisable to replant an existing coffee garden or block with new coffee. Replanting can be necessary for several reasons:

- The coffee trees are old, and have become low-yielding, broken or damaged;
- The coffee trees have undergone so much recycle pruning that generating healthy new uprights is becoming difficult;
- The coffee trees are badly infected by disease, such as coffee leaf rust;
- The coffee trees have died due to lack of fertiliser (very common in unshaded coffee).

Replanting a block of coffee is similar to establishing a new coffee garden (see Sections 5.2-5.4). The land must be cleared and drained, the planting holes marked out, and the coffee seedlings raised and planted.

### **5.5.2 Land clearance and draining**

The old coffee trees should be uprooted and removed or burnt. Burning is particularly important if the old trees were badly infected with coffee leaf rust or Pink disease. As much of the old root system as possible should be removed to avoid infecting the new coffee with root diseases.

The old drains should be cleaned out and new drains dug as necessary. Particular care should be taken to ensure appropriate discharge of drainage water.

### **5.5.3 Shade trees**

If the old shade trees are not too tall, they may be retained, but if they are old and very tall, they should also be cut down and removed from the site.

New shade trees should be planted as soon as possible in order to provide some shade for the young coffee. Temporary shade and windbreaks may also be planted (see Section 6.5).

### **5.5.4 Preparing the new coffee seedlings**

The variety of coffee to be planted should be decided and seeds obtained from the CIC RGSD. Replanting provides an ideal opportunity to plant the coffee leaf rust resistant variety, Catimor (see Section 3.2.6).

A nursery should be constructed, and seedlings raised as described in Section 4.

### **5.5.5 Marking out and planting the new seedlings**

The new coffee is best planted in the old coffee rows, particularly if the old stumps have not been completely removed. This will facilitate subsequent access to the coffee for maintenance and harvesting. Replanting in the existing coffee rows will also fit best with the old drainage system.

The disadvantage of replanting in the old coffee rows is that the new spacing options are limited. The easiest option is to simply use the old spacing, but consideration can be given to increasing the plant density within the old layout. If dwarf Catimor (or Caturra) is to be replanted, then the plant density will almost certainly be significantly increased (see Section 5.2.3 for options).

The planting holes should be dug and refilled, and the new coffee seedlings should be planted, as described in Sections 5.2.4 and 5.2.5 respectively.

### **5.5.6 Intercropping**

The cleared plot may be utilised for growing annual crops (but not sweet potato) before the coffee is planted, and intercropped for the first two years after the coffee is replanted (see Section 5.2.6).

## **6.0 MANAGEMENT OF YOUNG COFFEE**

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### **6.1 INTRODUCTION**

The early years of the coffee bush are vital to its future growth and productivity. Poor management practices, such as taking a heavy crop during establishment, can result in serious die-back of the primary branches and damage to the root system. Early cropping should be discouraged by removing the lower skirt branches if the lower primaries are carrying unsustainable crop, for which additional fertiliser cannot be provided.

During the first three years the coffee trees should be encouraged to develop a deep and extensive root system. Deep rooted trees can draw moisture from a greater depth of soil, whilst trees with an extensive root system can draw nutrients from a greater volume of soil. Trees with a deep and extensive root system can therefore bear heavier crops without die-back and are more drought resistant. By retaining soil moisture, mulching can assist in the development of a suitable root system. Coffee grown under good nutrient management is less susceptible to pests and diseases.

Pruning is an important aspect of shaping the tree for future productivity. A decision should be taken before planting on whether to raise the tree on single or multiple stems and pruning should be undertaken in the first year.

Unwanted suckers and excessive secondary growth should be removed by regular pruning as a means of training the tree to the desired shape for future productivity.

The anticipated yields for both the plantation and smallholder sector can be seen in Tables 7.1 and 7.2.

### **6.2 DEFINITION OF YOUNG COFFEE**

For the purpose of this Handbook, any bushes which have not carried their first main crop are defined as young coffee.

The age at carrying first crop can be affected by several factors, such as:

- Variety;
- Nutrition;
- Climate;
- Altitude;
- Management practices.

It is unwise to define young coffee too precisely, but generally it is tall varieties in their first 2 years and compact varieties in their first year.

### 6.3 NUTRITION OF YOUNG COFFEE IN THE FIELD

#### 6.3.1 Planting holes

Planting holes should be refilled with a mixture of approximately 4 parts topsoil to 1 part organic matter, such as well rotted coffee skins. If topsoil is insufficient to fill the hole then subsoil should be used mixed equally with organic matter. About 50 g of triple superphosphate should also be added to the planting hole mixture.

#### 6.3.2 Year one fertiliser schedule

Two fertiliser schedules are presented in Table 6.1 for the first year in the field, one for tall varieties, such as Arusha, Bourbon and Blue Mountain, and one for compact varieties, such as Caturra and Catimor. A typical plant density of 2,500 trees/ha has been assumed for tall varieties. For compact varieties application rates of ground applied fertiliser are increased in order to accommodate the greater planting density and more rapid growth, typical of such varieties.

**Table 6.1: Fertiliser schedules for tall and compact varieties of Arabica coffee during the first year in the field.**

DATE OF APPLICATION FROM PLANTING	QUANTITY AND TYPE OF FERTILISER	
	TALL VARIETIES	COMPACT VARIETIES
Day of planting		
6 weeks	Zinc foliar feed <sup>(1)</sup>	Zinc foliar feed <sup>(1)</sup>
6 weeks	70kg SOA <sup>(2)</sup> /ha	140kg SOA/ha
10 weeks	Zinc foliar feed	Zinc foliar feed
14 weeks	Zinc foliar feed	Zinc foliar feed
14 weeks	85kg DAP <sup>(3)</sup> /ha	170kg DAP <sup>(3)</sup> /ha
July	Standard foliar feed <sup>(4)</sup>	Standard foliar feed
August	Standard foliar feed	Standard foliar feed
September	Standard foliar feed	Standard foliar feed

- Notes: 1. Zinc foliar feed is described in Table 7.4.  
 2. SOA = sulphate of ammonia.  
 3. DAP = diammonium phosphate, the most appropriate fertiliser for young coffee (18% N, 46% P<sub>2</sub>O<sub>5</sub>).  
 4. Standard foliar feed is described in Table 7.4 and application is optional for the months of July, August and September.



Foliar feed should be applied until run-off commences. For young coffee, the amount of foliar feed applied per hectare would range from 100-200 litres, which should be sufficient for about 3,000-4,000 trees. Ground applied fertilisers should be applied around the drip circles of the young trees, which should be kept free of weeds where mulch has been applied.

### **6.3.3 Year two fertiliser schedule**

Only one fertiliser schedule is presented in Table 6.2 for the second year in the field. This is for tall varieties only, since compact varieties should produce a crop in their second year in the field, and should therefore receive the mature coffee fertiliser application.

Foliar feed should be applied until run-off commences. A 200 litre drum of foliar feed should be sufficient for one hectare or for about 3,000-3,500 trees. Ground applied fertilisers should be applied around the drip circles of the young trees.

**Table 6.2: Fertiliser schedule for tall varieties of Arabica coffee during the second year in the field.**

DATE OF FERTILISER APPLICATION	QUANTITY AND TYPE OF FERTILISER
September/October	85kg DAP/ha
November/December	70kg SOA <sup>(1)</sup> /ha
January/February	85kg DAP/ha
April/May	70kg SOA/ha
June/July	Standard foliar feed <sup>(2)</sup>
July/August	Standard foliar feed
August/September	Standard foliar feed

- Notes: 1. SOA = sulphate of ammonia.  
 2. Standard foliar feed is described in Table 7.4 and application is optional for the months of July, August and September.

### **6.3.4 Corrective fertiliser application**

Various nutrient deficiency symptoms may become apparent during the first two years in the field. Before considering corrective fertiliser applications however, it should be ensured that other factors are not causing the symptoms. In particular, inadequate drainage, competition from weeds, a lack of shade cover, and poor planting can result in unhealthy looking coffee trees. If specific nutrient deficiencies are suspected, the recommendations for corrective fertiliser applications to mature coffee (Section 7.3.4.7) are applicable.

As with nursery seedlings, young coffee in the field is particularly susceptible to leaf damage due to biuret toxicity. Home-made foliar feeds are not recommended, but if they are used, urea should be avoided if possible.

## **6.4 WEED CONTROL**

A weed is a plant growing where it is not wanted. Coffee growth and yields can be severely depressed by weeds which generally compete for water, nutrients and sunlight with young coffee. Other adverse effects of weeds include harbouring pests and diseases. Mulch provides the ideal form of weed control, but for both economic and practical reasons, the level of mulch applied is seldom sufficient to give full control of weeds. In high rainfall areas, where mulch depresses coffee yields, mulching as a cultural practice is not compatible with practical management. The use of mechanical weed control methods can increase soil erosion and/or compaction, while the use of selective herbicides may result in a build-up of resistant weeds. Weed control therefore, requires an integrated approach involving mulching as well as mechanical/manual and chemical methods.

### **6.4.1 Weed control in young coffee**

It is important that the control programme should start before planting, when perennial grasses such as kunai (*Imperata cylindrical*) and couch (*Cynodon dactylon*) in particular, must be eradicated. The newly established coffee seedlings should be kept weed-free to eliminate competition for soil moisture, nutrients and sunlight.

Regular hand weeding around the seedlings is most appropriate as the danger of injuring young trees is minimised. Careful application of herbicides within the inter-row avenues quickens the operation.

During the early establishment period it is essential to control weeds which may compete with the young trees. This generally means that they must be controlled at least within a radius of 50cm from the main stem, and this area will increase as the tree develops. Weed control at this stage is best achieved using a ring of mulch around the plant, which should not be placed closer than 10cm to the stem. Within this circle it is advisable to remove weeds by hand, outside this circle weeds may be removed by the use of a spade or bushknife; however, residual and contact herbicides may also be used. Care must be taken to avoid damaging young trees by using a spray guard or protective shield around the young tree, and suitable nozzle e.g. polyjet.

As the tree grows from seedling stage to maturity, its leaf canopy will play an increasing role in controlling weed growth. An additional advantage is an

improved root environment under the canopy provided by fallen leaves. However, once the trees begin cropping, the roots soon develop to cover the area between the rows. Thus weed control is mainly in the inter-row area.

From this stage on, weeds should be controlled through an integrated programme of mechanical e.g. slashing or cultivation, and chemical residual or contact herbicide methods.

#### 6.4.2 Weeds

Successful weed control can best be achieved by first identifying the weed species and then choosing the most suitable herbicide. Table 6.3 shows some of the common weeds in coffee growing areas of Papua New Guinea.

**Table 6.3: Some common weed species in coffee growing areas of Papua New Guinea**

BOTANICAL NAME	COMMON NAME
<b>Family: Amaranthaceae</b>	
<i>Amaranthus lividus</i> L.	Slender Amaranth
<b>Family: Carophyllaceae</b>	
<i>Drymaria cordata</i> L.**	
<b>Family: Commelinaceae</b>	
<i>Commelina benghalensis</i> ***	Wandering Jew
<i>Commelina diffusa</i> ***	Wandering Jew
<i>Murdannia nudiflora</i> L.	Day Flower
<b>Family: Compositae</b>	
<i>Ageratum conyzoides</i> L.**	Goat Weed
<i>Bidens pilosa</i> **	Cobbler's Pegs, Black Jack
<i>Crassocephalum crepidioides</i> **	Thick Head
<i>Eleutheranthera ruderalis</i>	
<i>Emilia prenanthoidia</i>	
<i>Emilia sonchifolia</i>	Purple Sowthistle, Milk Thistle
<i>Erigeron sumatrensis</i> **	Sumatran Fleabane
<i>Galinsoga parviflora</i>	Yellow Weed, Gallant Soldier
<i>Sonchus asper</i>	Spiny Sowthistle
<i>Synedrella nodiflora</i> L.*	Pig Grass, Synedrella
<b>Family: Convolvulaceae</b>	
<i>Ipomoea batatas</i> *	Sweet Potato, <i>kaukau</i>
<i>Ipomoea triloba</i>	
<b>Family: Cruciferae</b>	
<i>Cardamine hirsute</i> L.	Bitter Cress
<b>Family: Cyperaceae</b>	
<i>Cyperus rotundus</i> L.*	Nut-grass, Purple Nutsedge
<i>Cyperus aromaticus</i>	
<i>Cyperus bifax</i> ***	Giant Nutgrass

<i>Cyperus brevifolius</i> **	Short Kyllingia
<i>Cyperus cyperoides</i> L.**	
<i>Cyperus distans</i>	
<i>Fimbristylis dicotoma</i>	
<i>Kyllingia brevifolia</i>	
<i>Kyllingia polyphylla</i> Willd*	Navua Sedge
<b>Family: Euphorbiaceae</b>	
<i>Euphorbia hirta</i> L.	Asthma Plant, Sneeze Weed
<i>Euphorbia thymifolia</i> L.	Dwarf Spurge
<i>Phyllanthus niruri</i> L.	
<b>Family: Gramineae</b>	
<i>Axonopus compressus</i>	Carpet Grass, Sogeri Grass
<i>Brachiaria mutica</i>	
<i>Cynodon arcuatus</i> *	Giant Couch Grass
<i>Cynodon dactylon</i> L. Pers***	Cough Grass, Bermuda Grass, Star Grass
<i>Digitaria insularis</i>	Feather-top Grass
<i>Digitaria sanguinalis</i>	Giant Crab Grass, Hairy Finger Grass
<i>Digitaria setigera</i> **	Crab Grass
<i>Eleusine indica</i> L.	Goose Grass, Crowsfoot Grass, Wild Finger Millet
<i>Eragrostis tenuifolium</i>	Wiry Love Grass, Waghi Grass
<i>Imperata cylindrica</i>	Kunai, Sword Grass
<i>Melinis minutiflora</i> *	Molasses Grass
<i>Paspalum conjugatum</i> **	Thurston Grass, Sour Grass
<i>Paspalum orbiculare</i>	Paspalum
<i>Paspalum paniculatum</i> L.	Paspalum
<i>Pennisetum clandestinum</i>	Kikuyu Grass
<i>Setaria</i> spp.	Yellow Bristle Grass, Foxtail
<b>Family: Leguminosae</b>	
<i>Aeschynomene indica</i> L.	
<i>Casia alata</i> L.	Ringworm Shrub
<i>Desmodium carnum</i> (Gmelina)	Spanish Clover
<i>Desmodium purpureum</i>	
<i>Desmodium tortuosum</i>	
<i>Leucaena leucocephala</i>	Leucaena
<i>Mimosa invisa</i>	Giant Sensitive Plant
<i>Mimosa pudica</i> L.	Sensitive Plant
<b>Family: Malvaceae</b>	
<i>Sida microphylla</i>	
<i>Sida rhombifolia</i> ***	Broom Weed, Broomstick
<i>Urena lobata</i> L.	Pink Burr
<b>Family: Melastomaceae</b>	
<i>Clidemia hirta</i> L.	Kosters Curse
<b>Family: Oxalidaceae</b>	
<i>Oxalis corniculata</i> L.	Yellow Wood Sorrel
<i>Oxalis europaea</i>	
<i>Oxalis repens</i>	
<b>Family: Piperaceae</b>	
<i>Peperomia pellucida</i> L.	Peperomia

**Family: Portulacaceae**

*Portulaca oleracea* L. Pig Weed, Purslane

**Family: Polygonaceae**

*Polygonum nepalense*\*\* Slender Knotweed

*Polygonum orientale* L.

*Polygonum strigosum* Rough Knotweed

**Family: Polygalaceae**

*Polygala paniculata*

**Family: Rubiaceae**

*Hedyotis corymbosa* L.

*Mitracarpus villosus*

*Spermacoce laevis*

*Spermacoce repens*

**Family: Solanaceae**

*Physalis angulata* Bladder Cherry, Wild Cape Gooseberry

*Solanum nigrum* L. Black Nightshade

**Family: Urticaceae**

*Laportea interrupta* L. Hen's Nettle

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**KEY:** \* Difficult weed to control.  
\*\* Predominant weeds in coffee gardens.  
\*\*\* Predominant hard-to-kill weeds.

### 6.4.3 Herbicides

#### 6.4.3.1 Herbicide types

Herbicides can be classed as **selective** when they are used to kill weeds without harming the crop, or **nonselective** when their purpose is to kill all vegetation.

However, herbicides can also be classified as **contact** or **translocated (systemic)**.

- Contact herbicides. These kill the plant parts to which the chemical is applied and are most effective against annuals, those weeds that germinate from seeds and grow to maturity each year. Complete coverage is essential in weed control with contact herbicides.
- Translocated herbicides (systemic). These are absorbed either by roots or above-ground parts of plants and then circulate within the plant system to distant tissues. Translocated herbicides may be effective against all weed types, however, their greatest advantage is in the control of established perennials, those weeds that continue their growth from year to year. Uniform application

is needed for translocation herbicides, but complete coverage is not required.

Another method of classification is the **timing of herbicide application** with regard to the stage of crop or weed development. The three categories of timing of application herbicide are **pre-planting, pre-emergence and post-emergence**.

Note: *It is not advisable to mix contact and systemic herbicides. The contact herbicides kill the weeds and the translocated herbicides cannot be absorbed by the plant.*

#### 6.4.3.2 Characteristics of available herbicides

##### **Glyphosate (Roundup)**

Roundup is a non-selective, translocated, non-residual, post-emergence herbicide. It is very effective on deep rooted perennial species. Annual and biennial species of grasses, sedges and broad-leaved weeds are effectively controlled.

Toxicity: LD<sub>50</sub> – 4,900 mg/kg. May cause eye and skin irritation.

Rate: 0.50-4.50 litres/ha. General application rate.  
3.00 litres/ha. Specific application rate.

##### Absorption, translocation and response

It is absorbed by foliage and translocates throughout the plant.

The predominant effect is the inhibition of aromatic amino acid synthesis in the plant. This results in an increase in the level of free ammonia, ethylene and cellulose. Total free amino acids are increased and protein levels are decreased, resulting in the characteristic glyphosate injury symptoms. Another important enzyme induced is phenylalanine ammonialyase. This is an important enzyme for the production of phenolic compounds which inhibit growth of plants.

Symptoms are slow to develop and are evident 2-3 weeks following application. Plants affected develop a yellow-orange foliage followed by chlorosis and necrosis. Symptoms are delayed in the dark, because light is essential for glyphosate injury. There is also a 'witches broom' effect (multiple shoots), growth inhibition of rhizomes and stolons, leaf wilting and wrinkling.

Good results have been obtained when treating plants at full maturity. Annual weeds are controlled regardless of growth stage. Repeat application may be needed on tough and deep rooted perennials.

Annual weeds continue to germinate throughout the season so retreatment may be necessary.

#### Important weeds controlled

*Cynodon dactylon* (Couch Grass), *Digitaria arcuatus* (Giant Couch Grass), *Imperata cylindrica* (Kunai Grass), *Digitaria setigera* (Crab Grass), *Digitaria sanguinalis* (Giant Crab Grass), *Paspalum* spp., Sedges, *Portulaca oleracea* (Pig Weed) and most perennial, annual grasses and broad-leaved weeds.

#### Precautions

1. Do not spray green bark of coffee.
2. Do not apply if rain is expected within six hours, as it will reduce the herbicide's effectiveness.
3. Do not mix with dirty water, because clay particles deactivate glyphosate, reducing its efficacy.

#### Soil persistence

Roundup is biodegradable – it rapidly breaks down in the soil, with no residue build-up.

#### **Glufosinate-ammonium (Basta)**

Basta, a phosphate compound, is a contact herbicide with systemic activity used as a broad-spectrum, post-emergence herbicide.

Toxicity: LD<sub>50</sub> – 1,620 mg/kg

Rate: 1.5-5.0 litres/ha (3.25 litres/ha)

#### Absorption, translocation and response

Glufosinate-ammonia (Basta) is translocated within the leaves and not to other plant parts. It inhibits photosynthesis, and ammonium ions are accumulated in the leaves resulting in the foliage burning down. This herbicide controls a wide range of annual and perennial weeds (grasses, broad-leaved, ferns and shrubs).

On perennial weeds, burn down of foliage will occur, but plants will regrow from roots. Multiple applications may be necessary where perennial weeds are involved.

Symptoms of application are noticeable on weeds within 2-5 days.

#### Important weeds controlled

*Digitaria setigera* (Crab Grass), *Portulaca oleracea* (Pig Weed) and *Solanum nigrum* (Black Nightshade). The chemical is more effective on broad-leaved weeds than on grasses.

#### Precaution

Do not apply if rain is expected within six hours. Rainfall immediately after application will reduce the effectiveness.

#### Soil persistence

There is no soil activity, thus weed seeds and seedlings not yet emerged will not be controlled.

#### **2,4-D (2,4-dichlorophenoxy acetic acid)**

2,4-D is a selective, translocated phenoxy herbicide used mainly in post-emergence application to leaves. It is mainly active on broad-leaved weed species.

Toxicity: LD<sub>50</sub> – 400 mg/kg

Rate: 0.25-5.00 litres/ha (1.50 litres/ha)

#### Absorption, translocation and response

The herbicide is absorbed through the leaf surface and translocated throughout the plant, generally in the direction of carbohydrate (food) movement within the translocation system of the plant, leaving the root unharmed. New shoots will regenerate from the undamaged roots. Susceptible plants usually become malformed before they die.

#### Important weeds controlled

2,4-D can be used in coffee plots where broad-leaved annuals such as Thick Head (*Crassocephalum crepidioides*), Goat Weed (*Ageratum conyzoides*) etc. are abundant. This herbicide gives good control of perennial broad-leaved weeds such as *Commelina diffusa* (Wandering Jew) and *Sida rhombifolia* (Broom Weed).

#### Precautions

It is volatile, so special care must be taken to avoid drift because the highly volatile esters will cause injury to coffee. Therefore, low pressure should be used while spraying to avoid drift.

#### Soil persistence



Low concentrations of 2,4-D are decomposed in the soil, persisting only 1-4 weeks, in warm wet conditions.

### **MCPA (Methoxone)**

MCPA is a post-emergence, selective, translocated phenoxy herbicide, mainly active on broad-leaved weed species.

**Toxicity:** LD<sub>50</sub> – 700 mg/kg. May cause irritation to eyes and skin.

**Rate:** 0.20-2.00 1/ha (1.5 1/ha)

### **Absorption, translocation and response**

It is absorbed through the leaf surface and translocated throughout the plant. The plants become malformed before they die.

### **Important weeds controlled**

*Cyperus* sp. (sedges), *Portulaca oleracea* (Pig Weed) and many other broad-leaved weeds. Safer on crops than 2,4-D. It is more effective on **some** broad-leaved weeds than 2,4-D, but considered less effective on **most** broad-leaved weeds.

### **Precautions**

Formulated as amine salts and low volatility esters, and therefore not as volatile as 2,4-D. However, drift has to be avoided to prevent injury to coffee trees.

### **Soil persistence**

Persists in the soil for 8-12 weeks or longer.

### **Triazines**

Atrazine (Gesaprim), Ametryne (Ametrex) and Simazine are triazine compounds.

### **Absorption, translocation and response**

These herbicides are taken up by the roots and more exclusively through the transpiration stream. When applied on the foliage they move and collect at the leaf margins in dicotyledons, and throughout the leaf in monocotyledons. Seeds absorb these chemicals on the seed coat, and with germination, the chemicals move into the seedlings.

These chemicals inhibit growth of plants by blockage of photosynthesis. There is chlorosis followed by necrosis (nitrite injury).

### **Atrazine (Gesaprim)**

**Toxicity:** LD<sub>50</sub> – 1,800 mg/kg

**Rate:** 0.20-2.00 kg/ha (2.00 kg/ha)

Atrazine is a selective herbicide used pre-emergence.

#### **Absorption and translocation**

Moisture activates the chemical. It is usually considered more toxic than other triazines. Acts mainly through the roots but there is some activity through foliage contact. Resembles Simazine, but is faster acting under low rainfall conditions. Does not prevent germination, but kills weeds after being absorbed by the roots.

#### **Important weeds controlled**

*Digitaria setigera* (Crab Grass), *Setaria* spp (Foxtail), *Cyperaceae* spp (Sedges), *Portulaca oleracea* (Pig Weed) and many broad-leaved weeds and grasses.

#### **Precautions**

The chemical can be leached downwards, causing damage to coffee roots.

#### **Soil persistence**

Residues may remain in the soil for one year.

### **Ametryn (Ametrex)**

Ametryne is a triazine compound, used as a pre- and post-emergence herbicide. It has a broad spectrum of activity against broad-leaved and grass weeds.

**Toxicity:** LD<sub>50</sub> – 1,000 mg/kg

**Rate:** 0.60-3.00 kg/ha (1.5 kg/ha)

#### **Absorption, translocation and response**

Absorbed through the root system as the weeds germinate. Therefore, weeds will emerge before dying. There is also considerable activity through foliage contact. Mature weeds of certain species will be controlled by post-emergence application.

### Important weeds controlled

*Cyperaceae* spp (Sedges), *Eleusine indica* (Crowsfoot grass), *Portulaca oleracea* (Pigweed), *Digitaria setigera* (Crab grass) and most grasses and broad-leaved weeds.

### Precautions

Avoid excess application as the chemical moves vertically and laterally due to its high water solubility.

### Simazine

It is a selective triazine compound used as a pre-emergence herbicide. It is chemically related to Atrazine but has no post-emergence activity.

Its mode of action is through roots and shoots of emerging weeds. It does not prevent germination. Controls a broad spectrum of weeds.

**Toxicity:** LD<sub>50</sub> – 5,000 mg/kg. May cause slight eye and skin irritation.

**Rate:** 1.00-4.50 kg/ha (3.00 kg/ha)

Absorption, translocation and response (see notes on Triazines)

### Important weeds controlled

*Cynodon dactylon* (Couch Grass), *Digitaria* spp. (Crab Grass), *Emilia sonchifolia* (Purple Sow Thistle), *Portulaca oleracea* (Pig Weed) and many broad-leaved weeds and grasses.

### Precautions

1. Has long residual effect.
2. Requires moisture for its activation. Results may be disappointing if applied under dry conditions.

### Soil persistence

Tightly bound to soil particles. Micro-organisms break it down in about a year. Persists longer in dry, cold or low-fertility soils. May persist in soils for more than a year.

### Diuron

Diuron is a non-selective substituted urea compound generally used as a pre-emergence herbicide, but has some post-emergence activity on smaller weeds.

Diuron, as with Ametryne and Atrazine, has its post-emergence activity enhanced by a surfactant or wetting agent.

Toxicity: LD<sub>50</sub> – 3,400 mg/kg

Rate: 0.50-1.50 kg/ha (1.25 kg/ha)

#### Absorption, translocation and response

As with other soil applied herbicides, Diuron is absorbed by the roots and translocated via the transpiration stream to the leaves, the primary sites of photosynthesis.

The primary action of Diuron is to disrupt photosynthesis, giving rise to leaf chlorosis. Acute symptoms start with light green areas (within two days) and develop into a water soaked blotch after two days.

#### Important weeds controlled

*Digitaria setigera* (Crab Grass), *Sorghum halapense* (Johnson Grass), *Portulaca oleracea* (Pig Weed) and many others.

#### Precautions

1. Care must be taken using Diuron as it can be leached into the rooting zone of coffee causing serious damage.
2. Do not use on light sandy soils where coffee is grown.

#### Soil persistence

The chemical has low water solubility and is adsorbed by soil colloids. Resists leaching as a consequence and stays near the soils surface. It leaches more slowly than Monuron (another substituted urea compound).

May persist in soils for 12 months.

#### **Dicamba (Banex, Banvel)**

Dicamba is a benzoic acid derivative used as a pre-and post-emergence, selective, translocated herbicide.

Toxicity: LD<sub>50</sub> – 1,700 mg/kg

Rate: 0.25-9.00 litres/ha (4.50 litres/ha)

#### Absorption, translocation and response

It is a foliar and soil applied herbicide. It is readily absorbed by leaves and is translocated throughout the plant. The herbicide is also taken up by the roots and kills weeds as they germinate.

#### Important weeds controlled

Effectively controls many annual and perennial broad-leaved weed species. *Oxalis corniculata* (Yellow Wood Sorrel), *Polygonum* sp. (Knotweeds), *Portulaca oleracea* (Pig Weed) and many more broad-leaved weeds.

#### Precautions (see general precautions)

#### Persistence in soils

Dicamba is rapidly degraded in soils with 50% loss in less than 14 days.

### **General precautions on the use of herbicides**

- Do not spray foliage and green bark of coffee trees;
- Avoid drift onto coffee trees;
- Do not apply in the drip line of tree crops;
- Avoid mixing with dirty water, because the herbicide's effectiveness may be reduced;
- Never apply contact herbicide with translocated (systemic) herbicide, because contact injury to plants inhibits effective translocation of the systemic herbicide;
- Over-application of residual and/or soil applied herbicides leads to a build-up of residues in the soil. This can be injurious to coffee trees;
- Repeated use of any particular herbicide may lead to a build-up of specific weeds. Good herbicide rotation prevents this from happening.

### **6.4.4 Application of herbicides**

#### **6.4.4.1 Knapsack Sprayers**

A knapsack sprayer consists of a tank with pressurising device, a plastic hose or metal line and sprayer nozzle. It can be used for spraying a wide range of agrochemicals such as herbicides, insecticides, fungicides, and liquid fertilisers. A knapsack sprayer is carried on the back with the help of straps, firmly fastened over the shoulders.

Knapsack sprayers work on pressurised air, forced into an air-tight chamber, and then the liquid/mixture is released through a spray gun, via a nozzle which facilitates dispersion of the liquid/mixture to the target.

#### 6.4.4.2 Types of Knapsack Sprayers

There are various types of knapsack sprayers available, based on their capacity, pressurisation system as follows:

- Diaphragm Sprayers;
- Compression Sprayers;
- Piston Sprayers;
- Motorised Sprayers;
- Mist Blowers.



Plate 6.1: Diaphragm sprayer



Plate 6.2: Compression sprayer



Plate 6.3: Piston sprayer



Plate 6.4: Motorised sprayers



Plate 6.5: Motorised fogging sprayer or mist blower

#### 6.4.4.3 Essential Features of knapsack sprayers

Knapsack sprayers should have the following features:

- Filter in the lance grip;
- Large filling mouth;
- Filling filter with level indicator;
- Strong, adjustable, non-corrosive, oriented straps;
- Guide nut with washer for sealing and lubrication;
- Operating lever with ergonomic handle;
- Chrome plated brass or pvc lance;
- Resistant, light and ergonomic tank with handle for transport;
- Mechanical stirrer with device to fit the closing valve;
- Stainless steel balls in valve and sleeve;

- Rubber washer;
- Reversible handle fitting capacity: can be used in either hand;
- Large capacity and highly resistant pressure chamber;
- Corrosion-proof base;
- Connector for accessories;
- Trigger release valve;
- Pressure regulator that can be set at 1 to 3 bar.

#### 6.4.4.4 Pressure regulators

Pressure regulators or spray management valves are used to control and maintain a constant pressure that allows a fixed amount of liquid/mixture to flow from the knapsack through the lance and out of the nozzle (Figure 6.6). There are various types of colour coded spray management valves of varying sizes and shapes, as follows:

**Red** - used for herbicides;

**Yellow** - used specifically for herbicides (large droplets);

**Green** - used for insecticides, pesticides (very fine droplets);

**Blue** - can be used for herbicides, insecticides and fungicides.



**Plate 6.6: Spray management valves**

#### 6.4.4.5 Types of nozzles

Nozzles and spraying pressure determine the rate and type of spray produced. There are many different types of nozzles, designed for various purposes. They come in different sizes, shapes and colours; the operator should check the purpose of each nozzle as identified by colour.



VLV nozzles : used for spraying herbicides:



Conical nozzles : used for spraying herbicides, insecticides and fungicides.



Hollow Cone nozzles : used for spraying insecticides and fungicides



Full Cone nozzles : used for spot spraying of herbicides.

### **Plate 6.7 Polijet nozzles**

#### 6.4.4.6 Droplet size

Droplet size is determined by two factors:

- the sprayer operating pressure;
- the type of nozzle used.

For example, a low-pressure setting and a Polijet nozzle will give larger droplets. A high-pressure setting and a Hollow Cone nozzle will give finer droplets. Thus fungicides and insecticides are always applied with Hollow Cone nozzles and a high pressure setting (3 bar).



#### 6.4.4.7 How to calculate Total Volume Application Rate

Often, chemicals are wasted when too much chemical is used in the mix and or the volume of mix is too high or too low. It is, therefore, very important to know:

- the volume of chemical needed to cover a particular area;
- the volume of water needed;

Therefore, the farmer should know how to calculate the Total Volume Application Rate (TVAR) in litres/ha.

$$\text{TVAR} = \frac{\text{Flow rate (litres) per minute (FR)}}{\text{Swath width (m) of nozzle (SW) x walking speed (WS)}} \times 10,000 \text{ m}^2$$

**Example 1. A Green Polijet nozzle** has a flow rate of 1.2 litres/minute and a swath width of 1.2 metres. Thus, with the operator walking at 40 metres per minute the TVAR is calculated as follows:

$$\text{TVAR} = \frac{\text{FR}}{\text{SW} \times \text{WS}} \times 10,000 = \frac{1.2}{1.2 \times 40} \times 10,000 = \mathbf{250 \text{ litres/ha}}$$

The volume of chemical needed can be calculated from the volume to be mixed in each litre of water.

#### 6.4.4.8 Care and Handling of Agro-chemicals

Agro-chemicals refer to chemicals that are mainly used in agricultural operations such as herbicides, pesticides, animal drugs (veterinary chemicals), fungicides, insecticides, molluscicides, rodenticides etc.

Chemicals can be dangerous when they enter the blood stream and they can be absorbed through the skin (dermal), nose (inhalation), mouth (oral) and eyes. Therefore all chemicals have a warning or 'signal header' at the top of their labels.

The Signal Header is a warning on how to use the chemical:

**S4:** Limited to animal health products.

**S5:** Caution: Keep out of reach of children – Read Instructions carefully

**S6:** POISON

**S7:** DANGEROUS POISON

The Lethal Dose (LD<sub>50</sub>) and Lethal Concentration (LC<sub>50</sub>) is the dose or concentration at which 50% of the test population, for example rats or mice, which were subjected to the test, were killed in a laboratory environment. The lower the LD<sub>50</sub> or LC<sub>50</sub>, the more dangerous it is.

**Table 6.4: Chemicals and their toxicity**

Signal Header	Chemical	LD <sub>50</sub> (mg/kg)	Toxic Level
S5	Glyphosate	5,000	(Less Toxic)
	Pyrethrum	1,500	Lower the concentration, the greater the toxicity. (More Toxic)
	Copper Fungicides	1,131	
2-4-D	699		
S6	Chlorpyrifos	200	

A Soluble Concentrate (SC) is a liquid homogeneous pesticide formulation to be applied as a true solution of the active ingredient after dilution in water. An Emulsifiable Concentrate (EC) is a concentrated solution of the pesticide and an emulsifying agent in an organic solvent which will form an emulsion when added to water.

Steps in mixing agro-chemicals:

1. Always read the label before mixing or spraying chemicals.
2. Use an appropriate measuring jug or cylinder.
3. Wear appropriate personal protective equipment such as face mask/respirator, goggles, overalls, gumboots and rubber gloves, before handling chemicals.
4. Read the signal header and LD<sub>50</sub> or LC<sub>50</sub> to understand the toxicity level before measuring the chemicals.
5. Measure chemicals strictly according to the instructions on the label.

## **6.5 COVER CROPS/INTERCROPPING**

### **6.5.1 Cover crops**

During the first 2-3 years after field planting, coffee at normal spacing covers only a small proportion of the soil surface. Cover crops can be inter-planted in young coffee, particularly with wide-spaced arrangements, to smother weeds and protect the soil from erosion. They can also add nitrogen to the soil if a leguminous crop is used and the seed is inoculated with a culture of the appropriate nitrifying bacteria.

Cover crops may compete with the coffee for mineral nutrients, but these are eventually returned to the soil with the leaf litter. They can have an adverse effect on coffee through competition for moisture, especially in dry areas. However, this can be minimised by cutting back the cover crop at the end of the rains and leaving the foliage on the soil surface as mulch. If the cover crop

is a climbing vine, a circle should be kept clean-weeded around young coffee trees and the cover crop should be kept cut back around mature trees.

Cover crops used in coffee include, *Flemingia congesta*, *Pueraria javanica*, *Calapogonium* sp., *Desmodium* and *Stylosanthes gracilis*. Other crops such as *Crotalaria* sp., *Tephrosia* sp. and *Cajanus cajan* (Pigeon Pea), normally interplanted to provide shelter to young coffee, also help in smothering weeds.

### **6.5.2 Intercropping**

Intercropping with annual food or cash crops during the first two years following the planting of coffee seedlings in the field is possible without serious detrimental effects on the young coffee. Smallholders can utilise the inter-row spaces to plant food crops such as cabbage, broccoli, onion and banana, and these also act as temporary shade for the young coffee seedlings. The most suitable crops for intercropping are legumes such as peanuts and wing beans, because they add nitrogen to the soil. Tall annual crops such as corn should not be planted in young coffee, because they compete with the young seedlings for light.

Advantages of intercropping include:

- Farmers are encouraged to maintain their coffee seedlings as they take care of the annual food crops;
- Mulching materials are provided from the crop residues;
- Erosion and weeding requirements are reduced;
- The farmers make use of unproductive land to grow food crops;
- The farmers may generate income.

Some food crops that compete with the young coffee seedlings for moisture and nutrients, or host pests and diseases (such as sweet potato, *kaukau*, which hosts weevils), should be avoided. Some annual crops may impede the development of the coffee's 'surface plate' lateral roots, so the intercropped plants should not approach within 30 cm of the coffee trees.

## **6.6 SHADE AND SHELTER BELTS**

### **6.6.1 Introduction**

Shade can be either temporary or permanent. Temporary shade plants are quick growing, often hedge-planted in lines and will be kept for only the first 2-3 years of coffee establishment.

Permanent shade trees are more widely spaced and should eventually grow tall enough to provide an even shade over the coffee.

Shelter belts are usually planted at right angles to the prevailing wind and where the wind is strong and persistent, they should be considered permanent.

The provision of shade is up to the individual farmer, since it will depend on the intended future management level; but in areas where shelter belts are considered necessary, they must be provided.

## **6.6.2 Shade**

Shade trees are strongly recommended for all smallholder coffee gardens, because without regular applications of fertiliser unshaded coffee will die.

### **6.6.2.1 Advantages of shade trees**

- Reduction of incoming light intensity and daytime temperature at coffee level in hot areas: this helps to control the cropping level and reduce overbearing die-back in areas where rapid growth might otherwise lead to these problems;
- Reduction of diurnal temperature variation in areas where there is a marked difference between day and night temperatures: this reduces the incidence of distorted leaf growth as found in the 'hot and cold' and 'crinkle leaf' syndromes;
- Protection from low night temperatures and from frost incidence;
- Protection from wind and hail;
- Protection of the soil from the impact of falling rain, thus reducing soil erosion and nutrient loss;
- Reduction of soil temperature and evaporation;
- Reduction in growth of weeds, especially perennial grasses and sedges. The weeds found in shaded coffee are less harmful and are easier to control;
- Reduction of nutrient losses by leaching. Deep shade tree roots intercept leached nutrients, which are recycled by leaf litter, and extract nutrient reserves from the subsoils;
- Addition of nitrogen to the soil by the leaf litter and root nodules of nitrogen fixing shade trees;
- Tree roots can assist in breaking up hard pans and improve drainage;
- Source of firewood and building material.

### 6.6.2.2 Disadvantages of shade trees

- Under dry conditions, the shade trees compete with the coffee for soil moisture and nutrients;
- Shade trees require regular pruning and thinning to prevent the shade becoming excessive. This can be difficult and dangerous to carry out, and falling branches can cause considerable damage to the coffee trees;
- If the shade is dense, the coffee stems become etiolated and weak, and are liable to breakages. Production cycles may be shortened;
- The cropping potential of coffee under shade is limited due to reduced flowering resulting in reduced fruit set;
- The yield response to nitrogen fertilisers is limited. For this reason, intensively managed coffee is grown without shade, whereas coffee grown on a low input/low output system, as is the case of smallholders, is usually shaded and unfertilised;
- At higher altitudes and cooler areas, shade may alter night-time temperatures and maintain leaf wetness, thus producing more favourable conditions for germination of and infection by coffee leaf rust spores and other fungal diseases.

### 6.6.2.3 Management of shade trees

The ideal shade tree should provide high, light and even shade that reduces the light intensity by about 25%. The trees should be deep rooted so that they do not compete with the coffee for surface moisture and nutrients and so that they bring up nutrients from the subsoil and recycle it in the form of leaf fall. Many of the best shade trees add nitrogen to the soil through the action of nitrogen fixing bacteria in root nodules.

When shade trees are planted, it is usual to plant permanent shade trees at fairly wide spacing, inter-planted with quick-growing temporary shade trees at closer spacing. The temporary shade trees are gradually thinned out and eventually removed completely once the permanent shade trees are effective. The most widely used permanent shade trees in Papua New Guinea are *Albizia stipulata*, *Leucaena leucocephala*, and *Casuarina oligodon* ('yar'). Temporary shade trees include species of *Leucaena*, *Tephrosia* and *Crotalaria*.

Most of the *Leucaena* varieties are seriously defoliated by psyllids (an insect pest). However, three varieties of *Leucaena*, resistant to psyllids, are available from the Bulolo Forestry College. The varieties are Mexican Giant, Mexican Hybrid and *Leucaena diversiflora*.

While *Leucaena* is more adapted to the lower altitudes, it can grow well at high altitudes. *Albizzia* grows well at all altitudes, whereas *Casuarina* is more commonly grown in the highlands.

*Leucaena* and *Casuarina* ('yar') should be planted at a spacing of 10-12m, to be thinned to 20-24m at maturity. *Albizzia* should be planted at 20-24m and thinned to 40-48m. On poor soils shade trees may grow less well and so may not require thinning. All the trees should be regularly pruned, removing all branches to a height of 3-5m above the coffee bushes.

### **6.6.3 Shelter belts**

In exposed situations, a shelter crop should be inter-planted between the rows of coffee to give protection from the wind and sun for the first year or two until the permanent shelter belts are effective. Crops for this purpose can either be food crops such as pigeon peas (*Cajanus cajan*) or else erect cover crops such as *Crotalaria junces*, *Flemingia congesta*, *Tephrosia* sp., *Sesbania* sp. and banana.

Strong and persistent wind can do considerable damage to the coffee, causing stunted growth and rapid drying out during the dry seasons. In areas where this is likely to be a problem, lines of trees should be planted in the coffee at right angles to the prevailing wind and along the borders. Shelter belts should be thick and high, composed of stout trees which will stand up to winds. Shorter interplants should be provided to protect the ground level. A suitable tree for permanent windbreaks is *Casuarina*, which should be planted about 3m apart in the rows and later thinned to 6m. The distance between shelter belts should be three times the eventual height of the mature shade tree.

## **6.7 PRUNING**

During the first two years in the field, the early 'training' or 'formative' pruning is directed towards prevention of heavy cropping. In tall varieties, no crop should be allowed on one-year-old trees and only very little crop should be allowed on two-year-old trees provided proper fertilising is carried out. This is achieved by proper 'skirt' control (removal of the lower branches). Dwarf varieties will begin cropping during their second year in the field.

Training of the young tree to achieve the required framework should be carried out during the first two years in the field, the trees ending up with single or multiple stems. Better results are achieved if the young trees are capped during the first year.

For the multiple stem system, usual for tall coffee, seedlings should be capped at 30-45cm above ground level and 5cm above a pair of primary branches. It is advisable to cap maturing wood which is normally indicated by brown bark. Normally two uprights are required during the first cycle. Overgrown seedlings can be bent over and pegged to produce two uprights. In subsequent cycles, the plant densities determine the number of uprights.

Regular 'handling' and 'desuckering' should be carried out at this early stage to achieve the required canopy structure.





## 7.0 MANAGEMENT OF MATURE COFFEE

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### 7.1 INTRODUCTION

Two management levels are referred to in this section, with very different management requirements. The **'high input system'** represents unshaded coffee requiring high inputs and generating relatively high yields. It is found in PNG in the few remaining coffee plantations and in a small proportion of smallholder coffee, often former plantation or managed block coffee.

The **'low input system'** represents shaded smallholder coffee gardens that are actively managed albeit at a low level, and harvested regularly. This coffee is found in 'rehabilitated' or 'rejuvenated' or 'improved' smallholder coffee gardens. It does not include unmanaged or abandoned smallholder coffee.

This section focusses on nutrition and pruning of mature coffee, since weed management is described in Section 6 (Management of Young Coffee) and Disease and Pest Management are considered in detail in Sections 8 and 9 respectively.

### 7.2 DEFINITION

For the purpose of this Handbook, mature coffee bushes are tall varieties after year two, and compact varieties after year one. Mature coffee could also be defined as bearing coffee.

### 7.3 POTENTIAL YIELDS

During the first year of coffee establishment, no yield is normally expected, therefore production starts in the second year, but for tall varieties very little crop is achieved. Compact varieties can however produce a significant crop in the second year. The maximum production is realised during the fourth or fifth year. On attaining the maximum production levels, the yields start declining until the situation is arrested by a change of cycle whereby the old bearing heads are replaced by new ones. The yield decline is mainly caused by the fact that the stems grow too tall for effective management, and if pruning has been carried out correctly, the bearing wood is too far up the tree. It may therefore be possible to maintain yields in compact varieties for a longer period, enabling longer production cycles.

In tall varieties the production cycles are normally five years i.e. two years of establishment or raising suckers and three years of cropping (see Table 7.1);

while production cycles in compact varieties may be extended to 6 or 7 years (in this exercise a production cycle of 6 years is used) (see Table 7.2). During the change of cycle, the yields produced on the remaining bearing heads are between 50-65% of the maximum.

The figures presented here are purely hypothetical and do not represent any specific plantation or garden. However, they are based on realistic experiences and yield measurements in plantations, smallholder coffee and research situations. They represent **potential yields**; that is, yields that can be achieved if the coffee is correctly managed and the ripe berries are harvested regularly. It is assumed that production levels in the low input, rehabilitated smallholder sector are approximately 60% of those realised in the high input plantation sector. This is purely because the management levels are different, particularly in relation to the amount of fertiliser applied, the degree of pruning exercised and especially the shade density. Unfortunately, most smallholders are far from achieving these potential yields.

**Table 7.1: Potential yields in tall Arabica coffee (kg green beans per hectare per year)**

*YEAR IN THE FIELD	HIGH INPUT (PLANTATION) SECTOR	LOW INPUT (REHABILITATED SMALLHOLDER) SECTOR
1	0	0
2	250	150
3	1000	600
4	2250	1350
5	3000 a	1800 a
6	1300 b	780 b
7	1800 c	1080 c
8	2500	1500
9	3000 a	1800 a
10	3000 a	1800 a
11	1200 b	720 b
12	1800 c	1080 c
13	2500	1500
14	3000 a	1800 a
15	3000 a	1800 a

\* Refers to coffee year October – September

a Maximum yields after planting and change of cycle

b Yields solely from old bearing uprights during change of cycle.

c Yields mostly from old bearing uprights during change of cycle.

It is also assumed that all ripe cherries are harvested. In practice, a considerable amount of ripe cherries are either stolen or not harvested, being left on the trees to eventually fall to the ground.

These figures are based on healthy seedlings planted in the field early in year one and assuming 2 bearing heads in the first cycle and 3 bearing heads in subsequent cycles.

**Table 7.2: Potential yields in compact Arabica coffee (kg green beans per hectare per year)**

*YEAR IN THE FIELD	HIGH INPUT (PLANTATION) SECTOR	LOW INPUT (REHABILITATED SMALLHOLDER) SECTOR
1	0	0
2	1300	780
3	2500	1500
4	3500 a	2100 a
5	3500 a	2100 a
6	3000	1800
7	1300 b	780 b
8	2500	1500
9	3500 a	2100 a
10	3500 a	2100 a
11	3000	1800
12	1300 b	780 b

- \* Refers to coffee year October – September.
- a Maximum yields after planting and change of cycle.
- b Yields from old bearing head during change of cycle.

These figures are based on healthy seedlings planted in the field early in year one, one free growth bearing head in all cycles and slab pruning at the end of year 6.

## 7.4 NUTRITION

### 7.4.1 Introduction

Fertiliser applications are the biggest difference between the low input and high input systems. Shaded coffee can survive with little or no fertiliser application, but unshaded coffee will die without sufficient fertiliser. This section is therefore most relevant to the high input system, and the focus is very much on unshaded coffee. However, improved smallholder gardens are

likely to benefit from small amounts of fertiliser, and so this need is also addressed.

Fertiliser recommendations for a particular coffee garden or plantation block depend on many factors, including natural soil fertility, drainage, shade density, standard of husbandry, age of the coffee and anticipated yield. Recommendations for the industry as a whole must, therefore, be very general. They are intended to provide guidelines for the majority of growers who receive no other advice on fertiliser programmes, and as a yardstick against which growers may compare fertiliser advice from elsewhere. They are not intended to replace advice based on site specific soil and leaf analyses, yield data, and field observations. Indeed, the general recommendations should be modified where appropriate if site specific information suggests any abnormalities.

Although coffee yields may respond to fertiliser applications, for any particular location the response will level-off beyond a particular level of application, and further fertiliser will result in little or no additional yield. Furthermore, the response will be limited by other considerations such as climatic conditions, shade density, pruning policy and the degree of weed, pest and disease control achieved. It is not possible therefore to simply apply fertiliser to achieve desired yields. Rather the reverse is true. Yields are largely determined by other climatic and husbandry factors and the aim is to provide sufficient fertiliser to achieve the economically optimum yield attainable under those climatic and husbandry constraints.

To apply too little fertiliser would result in inadequate nutrition to support the developing crop and the coffee will be under stress. Partial dieback may occur and the following year's crop will be affected. To apply too much fertiliser would not make economic sense, since yields cannot be significantly further increased because of the over-riding climatic and husbandry constraints. It is also likely to generate excessive foliage.

The recommended approach to the nutrition of mature coffee is therefore to estimate the following season's yields (October–September), and then to provide sufficient fertiliser to adequately support this crop, and to meet the requirements of the trees. Yields can be increased by improved husbandry techniques, but always within the limits imposed by climatic factors and their effect on flowering. Yield estimates are based on the general condition of the coffee, the stage reached in the current production cycle, previous yield records and the amount of unripe cherries, pinheads and flowers. An initial estimate of yields can be made in September or October and a rather better

estimate, based on actual unripe cherries, in December or January. It is recommended therefore, that fertiliser programmes be provisionally derived in September and modified where necessary in January.

#### 7.4.2 Nutrients and nutrient ratio

Many nutrients (see Table 7.3) are required for the healthy growth of Arabica coffee, and in the appropriate proportions. However, nitrogen is the nutrient with the most marked effect on the growth of Arabica coffee, since it is required for both vegetative growth and crop production. A simple approach to deriving fertiliser programmes is therefore to determine the level of nitrogen required, and then to calculate the quantities of the other nutrients using appropriate ratios. The quantities of each nutrient thus derived are then modified where necessary as suggested by any evidence of specific deficiencies or toxicities.

**Table 7.3 Nutrients and their main functions in the coffee plant**

Nutrient	Main uptake as	Main requirement and use
Nitrogen (N)	NO <sub>3</sub> <sup>-</sup> , NH <sub>4</sub> <sup>+</sup>	Plant growth, protein, enzymes, hormones, photosynthesis
Phosphorous (P)	HPO <sub>4</sub> <sup>2-</sup> , H <sub>2</sub> PO <sub>4</sub> <sup>-</sup>	Energy compounds, root development, ripening, flowering
Potassium (K)	K <sup>+</sup>	Fruit quality, water balance, disease resistance
Calcium (Ca)	Ca <sup>2+</sup>	Cell walls, root and leaf development, fruit ripening and quality
Magnesium (Mg)	Mg <sup>2+</sup>	Chlorophyll, seed germination
Sulphur (S)	SO <sub>4</sub> <sup>2-</sup>	Amino acids and proteins, chlorophyll, disease resistance, seed production
Chlorine (Cl)	Cl	Photosynthesis, gas exchange, water balance
Iron (Fe)	Fe <sup>2+</sup>	Photosynthesis
Boron (B)	H <sub>3</sub> BO <sub>3</sub>	Development and growth of new shoots and roots, flowering, fruit set and development
Manganese (Mn)	Mn <sup>2+</sup>	Photosynthesis, enzymes
Zinc (Zn)	Zn <sup>2+</sup>	Hormones, enzymes, plant height
Copper (CU)	Cu <sup>2+</sup>	Chlorophyll, protein formation
Molybdenum (Mo)	MoO <sub>4</sub> <sup>2-</sup>	Nitrogen metabolism

Source: IPNI, 2012; Winston *et al.*, 2005.

In deriving fertiliser programmes for Arabica coffee, it is important to know the ideal ratios of the nutrients nitrogen, phosphorus and potassium required by the coffee as stated above, since the nutrient balance is as important as the

total amount of each nutrient available to the tree. It is usual to express the ratios of the nutrients N:P<sub>2</sub>O<sub>5</sub>:K<sub>2</sub>O, and for this 8.5:1:8.5 is currently suggested as the general recommendation for coffee in PNG. The closest compound fertiliser for coffee which is available on the market is 13:3:20 + MgO (Section 7.4.4.1), the difference being made up with application of straight fertilisers.

Should other appropriate compound fertilisers such as 10:5:20 become available on the PNG market, as stated again in Section 7.4.4.1, then according to Section 7.4.5, the ratios of the nutrients N:P<sub>2</sub>O<sub>5</sub>:K<sub>2</sub>O provided by the compound are 2:1:4. Thus ammonium sulphate only will be applied in October and April, whilst compound 10:5:20 will be applied in December and February.

### 7.4.3 Rates of application

Table 7.4 shows general recommended rates of application of N for anticipated yields ranging from less than 500kg green bean/ha to over 3,000 kg green bean/ha, for Arabica coffee in PNG. Rates of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O, based on ratios of 8.5:1:8.5, are also shown. Note that Table 7.4 shows rates of nutrients and not rates of fertilisers.

**Table 7.4: Recommended rates of nutrients for Arabica coffee in PNG.**

ANTICIPATED YIELD (kg GB/ha)	RATES OF APPLICATION (kg/ha/year)		
	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O
< 500	60	7	60
500-1000	60-100	7-12	60-100
1000-1500	100-140	12-16	100-140
1500-2000	140-200	16-23	140-200
2000-2500	200-300	23-35	200-300
2500-3000 +	300-400	35-46	300-400

Many growers will find it difficult enough to estimate their yields to within 500kg green bean/ha, however, those growers who are confident that they can estimate yields more accurately than this may calculate fertiliser rates on a pro-rata basis. Thus, for example, if a yield is estimated at 1750kg green bean/ha, the recommended rate of N application is 170kg N/ha/year.

### 7.4.4 Types of fertilisers

The nutrient requirements of coffee, discussed in the previous sections, can be provided by a wide variety of combinations of fertilisers. This section identifies the most appropriate for coffee nutrition in PNG.

#### 7.4.4.1 Compound fertilisers

It should be noted that bulk (or dry) blends, whereby straight fertilisers are mixed together, are not the same as granulated complete fertilisers, where each granule contains a relatively uniform mixture of nutrients. Cheaper, bulk blends should be used with care since uniform application of individual nutrients cannot be guaranteed, and they often degrade when not used quickly. Furthermore, there is no control over the quality of the individual constituents used in the blend. Nevertheless, good quality, granulated bulk blends are available in PNG, and these have a useful contribution to make to coffee nutrition. Such granulated bulk blends consist of a mixture of several, usually different coloured, granules of approximately the same size. Unlike granulated complete fertilisers, each granule is derived from only one straight fertiliser. However, provided the granules are well mixed, applications will contain the appropriate proportions of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O.

The simplest and most convenient way to ensure that coffee receives a balanced supply of nutrients is to use an appropriate compound (or complete) fertiliser, containing N, P, K, Mg and other elements. Of the formulations currently available in PNG, 13:3:20 + 2.5 (MgO) is the most suitable, bearing in mind that in mature Arabica coffee the requirement for phosphorus is relatively low and it could extract most of its requirements from the soil. Generally, the P<sub>2</sub>O<sub>5</sub> can be supplied solely by the compound fertiliser, and the appropriate levels of N and K<sub>2</sub>O are provided by additional applications of straight N and K fertilisers.

However, should a compound such as 10:5:20 become available in Papua New Guinea, there would be no need for additional K<sub>2</sub>O to be provided by straight fertilisers, as the total requirement will be provided by the compound (see Section 7.4.2).

Compound fertilisers are more expensive than the equivalent straight fertilisers, but require less fertilising rounds and therefore labour costs are reduced. Compound fertilisers also reduce to a minimum the possibilities of errors in calculating balanced rates of application.

The formulations express the percentage by weight of N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O and MgO respectively. Thus 13:3:20 + 2.5(MgO) contains 13% N, 3% P<sub>2</sub>O<sub>5</sub>, 20% K<sub>2</sub>O and 2.5% MgO. The proportion by weight of the other nutrients may also be included on the label, particularly sulphur (S) and boron (B). A very small supply of trace elements is also often included, and the balance of the fertiliser consists of filler. Thus, for example, an application of 250 kg of 13:3:20 +

2.5(MgO) would add  $250 \times 13\% = 32.5$  kg N,  $250 \times 3\% = 7.5$  kg  $P_2O_5$ ,  $250 \times 20\% = 50$  kg  $K_2O$  and  $250 \times 2.5\% = 6.25$  kg MgO.

#### 7.4.4.2 Nitrogen

For annual application in excess of 140kg N/ha, it is recommended for economic reasons that some of the nitrogen be applied as straight N fertiliser, such as urea, ammonium sulphate, or calcium ammonium nitrate. Since this corresponds to a yield of 1500 kg gb/ha, improved smallholders with **low/light shade** are recommended to apply compound fertilisers (smallholders with medium or heavy shade are not likely to achieve this yield level), and most plantations are recommended to apply a mixture of compound and straight fertilisers.

Urea contains 46% N, and is cheapest per unit of N. However, it must be applied to moist soil in order that it may be hydrolysed. Before hydrolysis, which takes 1-4 days, urea is very mobile, and leaching losses can be high. At soil pH values higher than 7,  $NH_4^+$  ions can be converted to  $NH_3$  (ammonia gas) and lost to the atmosphere by volatilisation if the soil is dry. Such losses can be considerably reduced if the urea is placed below the soil surface, by incorporation, deep placement or simply by downward movement due to rainfall.

Ammonium sulphate (21% N) has been shown to be as effective as urea in the tropics, and although slightly more expensive than urea per unit of N, it also contains 24% sulphur. Furthermore, ammonium sulphate when broadcast on the soil surface does not suffer substantial volatilisation losses. Leaching losses are also generally lower than with urea.

Thus, generally ammonium sulphate is recommended. However, long term use of ammonium sulphate can lead to increased soil acidity, and consequent reduction in availability of bases. If soil analysis indicates that this may be a problem, and soil pH (soil:water, 1:5) is below 5.0, then a less acidifying material such as calcium ammonium nitrate (26% N and 11% CaO) should be used, alternating with, or in place of, ammonium sulphate.

Another possible source of N, particularly if Mg is also a problem, is Nitromagnesia. In addition to 22% N, Nitromagnesia also contains 7% MgO and 11% CaO.

#### 7.4.4.3 Phosphorus

Since mature Arabica coffee has a relatively low requirement for phosphorus, the  $P_2O_5$  contained in compound fertilisers should be more than adequate.



If straight P fertiliser is required, then triple superphosphate or diammonium phosphate, which contain 44% and 46% citric-soluble  $P_2O_5$  respectively, are recommended. The slightly more expensive diammonium phosphate also contains 18% N; whilst triple superphosphate also contains 19% CaO and 1% S. Rock phosphate, which contains about 10% citric-soluble  $P_2O_5$  and 41% CaO has yet to be demonstrated in any way superior when applied to Arabica coffee and in PNG is considerably more expensive per unit of available P. It does however release non-citric-soluble  $P_2O_5$  (34%) into the soil over a longer period of time.

#### 7.4.4.4 Potassium

Muriate of potash is the only straight potassium fertiliser currently available on the market. It contains about 60%  $K_2O$ .

#### 7.4.4.5 Magnesium

If, despite the magnesium contained in the compound fertilisers, a problem with magnesium is still suspected, kieserite (magnesium sulphate, containing 27% MgO) should be applied at a rate of 50kg MgO/ha/year. Another source of MgO is Nitromagnesia, containing 7% MgO and 22% N.

#### 7.4.4.6 Foliar sprays

Foliar Nitrophoska (10:4:7 + 0.2 + TE) or Folifert (26:4:17 + 0.07 + TE) both provide a balanced range of all macronutrients, plus some micronutrients at rates of 6-8 litres/ha/application and 1.5 kg/ha/application respectively. Other suitable products are Bayfolan (11:8:6 + TE) which should be applied at a rate of 4 litres/ha/application, Spreigro (12:5:8 + 6.5 + TE) at 1.5 kg/ha/application, and Liquifert "Supergrow" (24:4:17 + TE) at 1.5 kg/ha/application.

It is not recommended to mix a general trace element foliar spray with the standard foliar applications, or to mix two trace element sprays together e.g. Zinc sulphate monohydrate mixed with Solubor. They are best applied separately. Fetrilon Combi 1 (higher in magnesium) or Fetrilon Combi 2 (higher in zinc and boron) are recommended products at rates of 0.6 kg/ha/application. The boron sources and recommended rates of application are Solubor at 90 g/ha/application or Borax at 180 g/ha/application; whilst for zinc they are zinc sulphate monohydrate at 60 g/ha/application, or zinc sulphate heptahydrate at 96 g/ha/application, or Zincol at 120 ml/ha/application.

All the above foliar rates assume that 300 litres of solution are applied per hectare to mature Arabica coffee. The recommended foliar feeds are summarised in Table 7.5

**Table 7.5: Recommended foliar feeds**

PRODUCT	QUANTITY PER 200 LITRES WATER
<b>STANDARD (MACRO AND MICRONUTRIENTS)</b>	
FOLIFERT	1000 g
or LIQUIFERT ("SUPERGROW")	1000 g
or SPREIGRO	1000 g
or BAYFOLAN	4 litres
or FOLIAR NITROPHOSKA	4 litres
<b>MICRONUTRIENTS</b>	
<b>MIXTURES</b>	
FETRILON COMB 1	400 g
or FETRILON COMB 2	400 g
<b>BORON SOURCES</b>	
SOLUBOR	60 g
or BORAX	120 g
<b>ZINC SOURCES</b>	
ZINC SULPHATE MONOHYDRATE	40 g
or LIBREL ZINC	20 g
or ZITRILON	60 g
or ZINC SULPHATE HEPTAHYDRATE	64 g
or ZINCSOL	80 ml

#### 7.4.4.7 Corrective fertiliser applications

Despite careful adherence to a balanced fertiliser schedule, it is still possible that some coffee will require additional applications of fertiliser in order to correct one or several nutrient deficiencies. Such deficiencies can be recognised either from soil or leaf analytical data (bearing in mind when the leaves were sampled), or by the occurrence of visual deficiency symptoms.

Nutrient deficiencies usually occur as a result of a heavier than expected crop, or soil-related factors.

If sub-optimal levels of **nitrogen**, **potassium**, **phosphorus** or **magnesium** are suspected, an immediate application of the standard foliar feed (see Table 7.5), followed by another four weeks later, will provide a more rapid response. Two applications for Foliar Nitrophoska 15:30:15 Solub at 6 litres/ha is particularly appropriate for a rapid response to phosphorus deficiencies.

Sub-optimal levels of **sulphur** are best corrected by applying nitrogen as ammonium sulphate.

**Zinc** deficiencies can be corrected by foliar applications. Three foliar applications, at monthly intervals of 600 g zinc sulphate monohydrate/ha, or 960 g of zinc sulphate heptahydrate/ha, or 300 g Librel zinc (zinc chelate)/ha, or 900 g Zitrilon (zinc chelate)/ha, or 1.2 litres Zincsol/ha are recommended.

**Boron** deficiencies can be corrected by either foliar or ground applied fertilisers. Three foliar applications, at monthly intervals, of 900 g Solubor/ha, or 1.8 kg Borax/ha, are recommended. Alternatively, 50 kg Solubor/ha, or 75 kg FB48/ha, or 100 kg Borax/ha, may be applied once to the soil.

**Molybdenum** deficiencies can be corrected by three foliar applications of 150 g ammonium molybdate/ha.

Where foliar application is recommended, the rates are given assuming that 1ha of mature coffee receives 300 litres of solution.

It should be noted that many factors other than simply inadequate supply can affect nutrient uptake. For example fixation of phosphorus or potassium by some soils, volatilisation of nitrogen, leaching of nitrogen or magnesium, inadequate drainage, inadequate soil moisture, nutrient imbalances and soil pH, can all have over-riding effects on nutrient uptake, which are not necessarily mitigated by applying more fertiliser.

For ease of reference, all fertilisers discussed in the preceding sections are summarised in Tables 7.6 and 7.7.

#### 7.4.4.8 Organic fertiliser - recycling coffee skins

Coffee skins, the 'waste product' resulting from pulping ripe coffee cherries, contain significant amounts of potassium and nitrogen – typically 1.5-2.5% nitrogen and 2.5-4.0% potassium (dry weight basis), depending on the amount of fertiliser previously applied to the coffee, plus smaller amounts of other nutrients. When applied to coffee in the field, coffee skins therefore make a very useful organic fertiliser for the coffee, and the high amounts of organic matter are also beneficial to the health and structure of the soil.

**Table 7.6: Ground applied fertilisers**

NAME OF PRODUCT	ABBREVIATION	TYPICAL ANALYSIS
<b>Compound fertilisers</b> 13:3:20 + 2.5	-	13% N, 3% P <sub>2</sub> O <sub>5</sub> , 20% K <sub>2</sub> O, 2.5% MgO
<b>Nitrogen fertilisers</b>		
Urea	-	46% N
Ammonium sulphate	AS or SOA	21% N, 24% S
Calcium ammonium nitrate	CAN	26% N, 11% CaO
Nitromagnesia	Nitromag	22% N, 7% MgO, 11% CaO
<b>Phosphatic fertilisers</b>		
Triple superphosphate	TSP	44% P <sub>2</sub> O <sub>5</sub> , 19% CaO, 1% S
Diammonium phosphate	DAP	46% P <sub>2</sub> O <sub>5</sub> , 18% N
Rock phosphate (Christmas Island)	CIRP (Grade C) Dust	10% P <sub>2</sub> O <sub>5</sub> , (soluble), 41% CaO 34% P <sub>2</sub> O <sub>5</sub> , (slow release)
<b>Potash fertilisers</b>		
Muriate of potash	MOP	60% K <sub>2</sub> O
<b>Magnesium fertilisers</b>		
Kieserite	-	27% MgO, 22% S
Dolomite	-	17% MgO
Nitromagnesia	Nitromag	7% MgO, 22% N, 11% CaO
<b>Boron fertilisers</b>		
Solubor	-	20.5% B
FB48	-	15.1% B
Borax	-	11.3% B

Every tonne of ripe cherries contains about 200 kg of dry matter, of which the coffee skins account for 50 kg. Therefore, the coffee skins from every tonne of ripe cherries contain about 1 kg of N and 1.6 kg K (or about 2 kg K<sub>2</sub>O).

Although many coffee farmers are aware of the potential benefits of returning coffee skins to their coffee gardens, most are discouraged by the high costs of handling, transporting and applying the product. Properly composted skins however is a far more attractive product to handle and transport since it is relatively light, friable and dry. Composted coffee skins are about one fifth of the weight of fresh skins, so every 50 kg of composted coffee skins contain

about 1 kg N and 1.6 kg K (or 2 kg K<sub>2</sub>O), small amounts of other nutrients, and lots of beneficial organic matter.

**Table 7.7: Foliar applied fertilisers**

NAME OF PRODUCT	TYPICAL ANALYSIS
<b>Complete foliar feeds</b>	
Folifert	26:4:17 + 0.07 + TE
Foliar Nitrophoska	10:4:7 + 0.2 + TE
Bayfolan	11:8:6 + TE
Spreigro	12:5:8 + 6.5 + TE
Liquifert (“Supergrow”)	24:4:17 + TE
Nitrophoska Foliar Solub	15:30:15
<b>General micronutrients feeds</b>	
Fetrilon Combi 1	9% MgO, 3% S, 1.5% Zn, 0.5% B
Fetrilon Combi 2	2% MgO, 2.8% S, 4% Zn, 1.5% B
<b>Zinc fertilisers</b>	
Zinc sulphate heptahydrate	22% Zn, 11% S
Zinc sulphate monohydrate	36% Zn, 18% S
Librel zinc	15% Zn (Chelate)
Zitrilon	10% Zn (Chelate)
Zincsol	16.7% Zn
<b>Boron fertilisers</b>	
Solubor	20.5% B
Borax	11.3% B
<b>Molybdenum fertilisers</b>	
Ammonium molybdate	56.3% Mo

To compost fresh coffee skins, they should be heaped and then turned and mixed every three or four days. Mixing in small amounts of urea will further facilitate the composting process. Covering the heap will help to retain the heat, but some air must also be able to escape. Suitable materials for covering the heap are banana leaves, hessian sacks or plastic sheets with a few 2cm wide holes pierced through them. Protecting the pulp from direct rainfall by constructing a simple, low roof, will keep the pulp dry and reduce leaching losses. Under these circumstances, the composting process should be completed in about three weeks. The compost can then be used as part of the

fertiliser programme, every 50 kg of compost replacing 1 kg N and 2 kg K<sub>2</sub>O of inorganic fertiliser.

#### **7.4.5 Timing of application**

It is recommended that the total annual dose of nitrogen is best applied in four equal applications in September/October, November/December, January/February and March/April, whereas potassium should be applied in two equal applications in November/December and January/February. However, due to differences in the rainfall distribution pattern which determines the main flowering, application schedules should be adjusted to meet the nutritional requirement of the growing coffee.

A straight nitrogen fertiliser therefore is recommended in September/October to assist with recovery from harvesting, and the growth of new stems, roots and flowers. Applications of compound fertilisers are required during the wet season when fruit set and major fruit growth are taking place (November/December and January/February), and straight fertiliser nitrogen is again recommended in March/April to prepare the coffee for the ripening phase.

The application of foliar sprays is particularly recommended for high yielding coffee in years of heavy crop or coffee showing stress signs, in January and March and during the drier period each year (July-September) particularly if the coffee is showing signs of die-back.

Foliar applied zinc fertiliser is recommended when new suckers are developing after a new production cycle is initiated. It is recommended that foliar zinc is applied soon after the first sucker selection; that would be four to six months after change of cycle was initiated, followed by monthly application for the next two months. Should the deficiency symptoms appear during the suckers' two years of establishment, foliar zinc must be applied at monthly intervals for at least three months.

#### **7.4.6 How to apply fertilisers**

Ground applied fertilisers should be applied in a circle around individual trees, not closer than 7cm to the stem in newly planted coffee, or 20cm in mature coffee, and extending to the edge of the drip circle. Ideally, it should be lightly mixed into the topsoil (particularly urea, compound fertilisers and superphosphates).

In practice, all too often fertiliser is merely thrown at the base of the tree, where it is unavailable for uptake by the majority of the roots. A practical

compromise is to broadcast the fertiliser under the canopy in a uniform layer, as thinly as possible.

Measuring the appropriate quantity of fertiliser to be applied to each tree is, in practice, very difficult. Precise applications, to the nearest gram, are not possible. A common practice is to calculate the number of bags of fertiliser required for a particular block, and then to distribute them as evenly as possible over the block. This relies on the good judgement of the workers applying the fertiliser and therefore often results in a very uneven application of fertiliser. In this situation, it is advisable to begin each alternate application at opposite ends of the block in order to avoid one end always being under fertilised.

If possible, containers such as fish tins cut to the appropriate size, should be used to apply the desired quantity of fertiliser to each tree. Nevertheless, even this can lead to considerable rounding errors.

Ground applied fertilisers should not be applied during the drier season since there is often insufficient moisture available near the surface to enable the nutrients to go into solution and thereby be taken up by the trees. There is also little point in applying fertilisers to inadequately drained land, or to land containing grasses or weeds.

Foliar applied fertilisers are most beneficial during the drier season. However, they may also be applied during the wet season, although the risk of being washed from the leaves by heavy rain is obviously greatly increased. Foliar fertiliser should be applied evenly to the entire tree, to the point of runoff. Typically, one hectare of mature coffee will require about 300 litres of solution.

#### **7.4.7 Fertiliser programmes**

By considering the nutrient requirements of coffee, the recommended fertilisers and the ideal time of application, it is possible to derive fertiliser programmes for Arabica coffee in PNG. Table 7.8 contains summaries of fertiliser programmes for two different levels of management, namely improved (or rehabilitated) smallholder with low/light shade and unshaded commercial (plantation) coffee.

Two examples – an improved smallholder and a commercial coffee estate are presented below in order to illustrate how Table 7.8 used in conjunction with Table 7.4 and the recommendations relating to fertilisers, can be used to prepare a generalised fertiliser programme for Arabica coffee at any level of

production in PNG. Section 7.4.7.3 considers the needs of more typical smallholders.

#### 7.4.7.1 A commercial plantation

It is assumed that commercial coffee managers are able to estimate yields with a reasonable degree of reliability, and will know the number of trees per ha for each of their blocks of coffee. The following example is for a block with coffee at a density of 2,667 trees/ha and with an anticipated yield of 2,000 kg green bean/ha.

From Table 7.4 it can be seen that the recommended rates of application of nutrients for an anticipated yield of 2,000 kg green bean/ha are 200 kg N/ha, 23 kg P<sub>2</sub>O<sub>5</sub>/ha and 200 kg K<sub>2</sub>O/ha. Table 7.8 suggests a fertiliser programme of applications of straight N and straight K in September/October, compound fertiliser in November/December and January/February and straight N in March/April, and foliar fertiliser in December/January and February/March **only** for heavily bearing coffee, or coffee showing signs of stress and foliar fertiliser in June/July, July/August and August/September **only** for coffee showing signs of die-back. From section 7.3.4, recommended fertilisers are, for example, 13:3:20 + 2.5(MgO), ammonium sulphate, muriate of potash and Folifert.

From section 7.3.5 it is recommended that potassium is applied in two equal applications. This would be ideal if a compound on the market contains two times as much K<sub>2</sub>O as N, and a lesser amount of P<sub>2</sub>O<sub>5</sub>, e.g. a compound of 10:5:20. However, as one is restricted by the ideal compound available on the market, the closest being 13:3:20 + 2.5(MgO), it is recommended that 77% of the total potassium requirement is applied as compound in equal applications in November/December and January/February, whilst, the remaining 23% is applied as straight K in the form of muriate of potash in September/October, along with ammonium sulphate.

One quarter of the recommended annual application of N is 50 kg/ha, which is equivalent to 385 kg 13:3:20 + 2.5(MgO)/ha or 238 kg ammonium sulphate/ha. The two applications of compound fertiliser also supply 385 x 20% = 77 kg K<sub>2</sub>O/ha/application (total 154 kg K<sub>2</sub>O/ha), which leaves 46 kg K<sub>2</sub>O/ha to be supplied by straight K fertiliser. This is equivalent to one application of 77kg muriate of potash/ha. Phosphorus (23 kg/ha) and magnesium (31 kg/ha) are also supplied by the compound fertiliser and sulphur (114 kg/ha) by the ammonium sulphate. The foliar fertiliser application(s) of, for example Folifert,



**Table 7.8: Generalised fertiliser programmes for Arabica coffee in Papua New Guinea**

COFFEE GROWER TYPE			Improved Smallholder	Commercial Plantation	
TYPICAL YIELD (kg green bean/ha)			1000-1500	> 1500	
MONTH	ACTIVITY		FERTILISER PROGRAMME <sup>(3)</sup>		
SEP/OCT	Onset of rains Main flowering			Straight N Straight K	
OCT/NOV	H e a v y  r a i n s  p e r i o d	Growth of new stems	Compound fertiliser		
NOV/DEC		Fruit set		Compound fertiliser	
DEC/JAN		Fruit growth			Folifert <sup>(1)</sup>
JAN/FEB					Compound fertiliser
FEB/MAR		Maintenance pruning			Folifert <sup>(1)</sup>
MAR/APR					Straight N
APR/MAY		Main harvest			
MAY/JUNE					
JUNE/JULY		Main pruning			Folifert <sup>(2)</sup>
JUL/AUG					Folifert <sup>(2)</sup>
AUG/SEP	Folifert <sup>(2)</sup>				

- Notes:
1. Foliar applied where the coffee is bearing a heavy crop or showing stress signs.
  2. Foliar applied where the coffee is showing signs of die-back.
  3. The fertiliser programme can be brought forward or back, depending on the climatic conditions, which stimulate the main flowering.

supply relatively small but timely, amounts of all macronutrients, as a supplement to the main applications of ground fertiliser and necessary micronutrients should their application be required. Such a balanced programme of applications of nutrients should suffice under conditions typical of the coffee growing areas of PNG, however, additional appropriate fertiliser may be applied in response to evidence of any shortages of specific nutrients, as explained in Section 7.4.4.7.

Since there are 2,667 trees/ha, the fertiliser programme can be summarised as in Table 7.9.

**Table 7.9: Summary of general fertiliser programme for a commercial plantation producing 2,000kg green bean per ha with a tree density of 2,667 trees/ha.**

MONTH	FERTILISER	APPLICATION/HA (kg)	APPLICATION/TREE (g)
SEP/OCT	Ammonium sulphate	238	89
SEP/OCT	Muriate of potash	77	29
NOV/DEC	13:3:20 + 2.5	385	144
DEC/JAN	Folifert <sup>(1)</sup>	1.5	110 ml <sup>(3)</sup>
JAN/FEB	13:3:20 + 2.5	385	144
FEB/MAR	Folifert <sup>(1)</sup>	1.5	110 ml
MAR/APR	Ammonium sulphate	238	89
JUN/JUL	Folifert <sup>(2)</sup>	1.5	110 ml
JUL/AUG	Folifert <sup>(2)</sup>	1.5	110 ml
AUG/SEP	Folifert <sup>(2)</sup>	1.5	110 ml

- Notes:
1. Foliar applied where the coffee is bearing a heavy crop or showing signs of stress.
  2. Foliar applied where the coffee is showing signs of die-back.
  3. Assume for foliar applications, 300 litres of solution is applied per hectare to mature coffee.

Application of coffee skins will slightly reduce the amounts of N and K fertilisers applied, since every 50 kg of composted coffee skins applied will reduce the inorganic fertiliser requirements by 1 kg N and 2 kg K<sub>2</sub>O. The greatest benefit however will be to the health and structure of the soils.

#### 7.4.7.2 An improved smallholder

Before it is possible to derive a fertiliser programme, it is necessary to know the anticipated yield. For the sake of an example, it will be assumed that the anticipated yield is 1,200kg green bean/ha (such a yield would be likely with light shade only). Extrapolating from Table 7.4, it can be seen that for such a yield, the suggested rates of application of nutrients for the year are 116 kg N/ha, 13.6 kg P<sub>2</sub>O<sub>5</sub>/ha and 116 kg K<sub>2</sub>O/ha. From Table 7.8, it is recommended that an improved smallholder should provide the appropriate levels of nutrients for his coffee by two equal applications of compound fertiliser, the first in October/November and the second in January/February. Section 7.4.4.1 recommends that, if possible, 13:3:20 + 2.5(MgO) be used, and explains how the rate of application of fertiliser is related to the rate of application of nutrients. Since 13:3:20 + 2.5(MgO) contains 13% N, the desired annual rate of

application of 116 kg N/ha would be provided by  $116 \times 100/13 = 892$  kg compound fertiliser/ha. Note that more than the necessary quantity of  $K_2O$  ( $892 \times 20\% = 178$  kg  $K_2O$ /ha) and  $P_2O_5$  ( $892 \times 3\% = 27$  kg  $P_2O_5$ /ha) than the desired 116 kg  $K_2O$  and 13.6 kg  $P_2O_5$ /ha are provided.

Thus, an appropriate fertiliser programme would be 446 kg 13:3:20 + 2.5(MgO)/ha in October/November and 446 kg 13:3:20 + 2.5/ha in January/February. Rates per tree can be calculated by dividing by the number of trees per ha. If the spacing is 2.74m x 2.74m (9ft x 9ft) there should be 1,332 trees/ha, and therefore  $446 \text{ kg}/1332 = 335$  grams compound fertiliser/tree should be applied in both November and February. Note that this rate per tree is applicable no matter how large or small the garden may be. If the spacing is irregular, the actual number of trees must be counted and divided by the measured area of the garden (in ha) to give the number of trees/ha, from which application rate/tree can be calculated.

In practice, many smallholders will not be able to estimate their yield, will not know the area of their garden, or be able to measure out their fertiliser applications. Therefore, a simple rule of thumb for such growers is to apply 300 g compound fertiliser per tree in November and February. This can be measured approximately by applying two 5.5 oz (155 g) fish tins full of compound fertiliser to every tree.

Application of coffee skins is of particular relevance to smallholders since every 50 kg of composted coffee skins contains 1 kg N and 2 kg  $K_2O$ . The 1,200 kg GB/ha yield assumed for an improved smallholder, would require 7,500 kg ripe cherry, which would generate 1,850 kg fresh coffee skins, or 370 kg composted coffee skins, containing about 8 kg N and 16 kg  $K_2O$ .

Any smallholder, no matter how much coffee they produce, would be advised to utilise his/her coffee skins by spreading them evenly throughout their coffee gardens. Composted coffee skins are the most efficient, but if fresh coffee skins are used, care should be taken to avoid touching the coffee tree trunks since fresh coffee skins are acidic.

#### 7.4.7.3 Typical smallholders

The improved smallholder in Section 7.4.7.2, with lightly shaded coffee, would be a high yielding smallholder. His/her coffee will require regular applications of fertiliser to remain healthy, as recommended. However, most improved smallholders will have moderately shaded coffee, which will yield considerably less. Most other smallholders with unimproved coffee will have moderate to

heavy shade, and low yields. These two categories of coffee grower currently represent the majority of the coffee industry in Papua New Guinea.

Improved smallholders with moderately shaded coffee may produce up to 800 kg green bean/ha. According to Table 7.4 they should therefore provide their coffee with up to 80 kg N and 80 kg K<sub>2</sub>O/ha. A production level of 800 kg GB/ha would generate 250 kg composted coffee skins/ha, containing 5 kg N and 10 kg K<sub>2</sub>O/ha. The rest of the fertiliser requirements could be provided by two applications of 308 kg 13:3:20+2.5(MgO) in October/November and January/February. At a tree density of 1,332 trees/ha, this would be equivalent to a rate of 230 g /tree. A simple rule of thumb would be to apply one 5.5 oz (155 g) fish tin full of compound fertiliser to each tree in October/November and January/February.

Unimproved smallholders with medium to heavy shade will be producing low yields of less than 350 kg GB/ha, and so will probably not need to apply any fertiliser to their coffee, particularly if they are shaded by Yar trees (which fix nitrogen from the air). The nutritional needs of the garden will probably be provided by the nitrogen fixed by the Yar trees, the leaf litter from the coffee and shade trees, unharvested ripe cherries falling to the soil and decomposing, and recycling of the coffee skins. However, when possible, an application of compound fertiliser, at a rate of one 5.5oz (155g) fish tin full per tree, would always be beneficial, provided the coffee garden has been weeded first.

## **7.5 PRUNING**

Pruning is an important aspect of coffee management as it influences the tree growth and responses to weeding, mulching and fertiliser application, while inducing favourable conditions for pest and disease control. Pruning is also a means of exercising crop control. The pruning practices recommended here are based on experiences and practices in other coffee growing countries, but they have been tried and tested successfully in Papua New Guinea, in formal trials and by coffee growers small and large.

### **7.5.1 Pruning operations**

- **Training (formative pruning).** Capping of young seedlings during the first two years of field establishment.
- **Skirting.** Cutting up (removal) of primary branches below 60cm on the stem, during the first two years of establishment or during change of production cycle.
- **Handling.** Removal of excessive secondary and tertiary growth.

- **Desuckering.** Removal of suckers and secondary branches along the primaries within 20cm of the main stem.
- **Centring.** Removal of suckers and secondary branches along the primaries within 20cm of the main stem.
- **Maintenance/main pruning.** Removal of exhausted, dead wood and interlocking branches, following crop harvest. This includes handling, desuckering and centring.
- **Stumping.** Removal of all the bearing uprights (heads, stems) at the end of a production cycle.
- **Recycle Pruning.** Removal of one or two uprights and primary branches on the remaining upright during the change of the production cycle.
- **Sucker selection.** Identification of suitable suckers and removal of unwanted suckers during the change of production cycles.

These pruning activities require the following pruning equipment:

- A pair of secateurs;
- A pruning saw;
- A measuring stick;
- A power saw.

### **7.5.2 Pruning objectives**

- To concentrate the vigour of the tree into those parts that produce the most crop. New wood produces more crop than old wood.
- To assist in the production of regular crops. Pruning reduces the risk of over-bearing which results in biennial bearing due to crop strain on the tree.
- To facilitate harvesting. In its natural conditions, the coffee tree can grow tall and bushy, presenting difficulties in cherry harvesting.
- To make spraying more efficient and economical. This is important in both disease and pest control.
- To produce a less favourable microclimate for pests and diseases. Some pests and fungal diseases, such as coffee leaf rust, thrive best in the humid environment of unpruned trees.
- To rejuvenate old trees. As the bearing wood grows older, production declines. As the trees grow taller, harvesting, pruning and spraying become more difficult.

### **7.5.3 Pruning systems**

Basically, there are two pruning systems, **single stem, and multiple stem.**

A single stem system, has one bearing upright (head, stem) per tree.

In a multiple stem system, there are two or more bearing uprights (head, stem) per tree. Production cycles are changed every 4 to 7 years. At low altitudes (and with Robusta coffee), where growth is fast due to the hotter climate, change of cycle is recommended after 4 to 6 years of cropping, while at higher altitudes with cooler climates, the cycle can be extended to 6 to 7 years of cropping depending on coffee variety and management.

Note: Once the single and multiple stem pruning systems are established, the yield differences are insignificant. Under smallholder conditions, the multiple stem pruning system is recommended as it is easier to manage, and is also cost effective.

### **7.5.4 Factors that influence the choice of the pruning system**

- **Growth rate**

At higher altitudes, the growth is slower and internodes become shorter, with the result that stems become rigid and do not bend outwards to facilitate picking on the multiple stem system, and so a single stem pruning system may be appropriate.

- **Spacing**

Pruning is very closely integrated with spacing in many aspects. At wide spacings, more bearing heads per tree are allowed because there is more room for the spreading of branches. At closer spacings, a single stem pruning system will be easier to manage.

- **Variety**

Generally dwarf coffee varieties are best suited to single stem pruning systems and tall coffee varieties are best suited to multiple stem pruning system.

- **Management**

Local management requirements may dictate the pruning policy. These include the size of the holding, cultural methods, terrain, drainage, spray equipment etc. and all influence the choice of pruning system in one way or other.

### **7.5.5 Pruning practices**

Pruning of mature tall coffee should start during the third year (during the second year for compact varieties) after field planting or change of production cycle, i.e. after complete stumping or recycle pruning. The main operations involve main pruning, handling and desuckering. Each of these terms is explained below:

#### **7.5.5.1 Main pruning**

Main pruning is done annually immediately after harvesting the main crop. This is the time to prepare the trees for the next flowering. The main pruning should coincide with the drier period between August and October. The operations carried out during the main pruning are:

- Annual removal of the lower primary branches from the main stem(s), depending on the stage of pruning, to maintain a desired length of the bearing head.
- Removal of suckers (upright growth) i.e. desuckering.
- Removal of secondary growth within 20cm of the main stem(s). The combined effect of this and desuckering is to open the centre of the coffee tree.
- Removal of any secondary and tertiary branches growing towards the stems, downwards and upwards.
- Removal of interlocking branches.
- Arrangement of the remaining secondary branches on alternate sides of the primary branch up to a maximum of six per primary. Only 2-4 of these secondary branches should be allowed to carry a crop each year.

Note: Precaution against Pink disease

In areas with Pink disease problems and Fusarium Bark disease, the pruning saws and secateurs should be disinfected by dipping in any fungicide after dealing with diseased trees to minimise the spread of the disease. All infected material should be carefully removed and burned on site if possible.

#### **7.5.5.2 Number and length of bearing heads**

The number of bearing heads is determined by tree population, and the length of bearing head is derived by removing all primaries that have carried two crops.

**Table 7.10: Tree density and bearing heads**

DENSITY TREES/HA	BEARING HEADS PER TREE
< 2000	4
2000 – 3000	3
3000 – 4000	2
> 4000	1

#### 7.5.5.3 Handling

The onset of rains is followed by flowering and vegetative secondary growth. The unwanted vegetative growth should be removed at intervals of 2 to 4 months (See Section 7.4.5.1). Failure to remove this vegetative growth results in serious competition for both water and nutrients, between the developing berries and vegetative growth. This competition has an adverse effect on the size of the beans, which has a direct impact on bean quality.

#### 7.5.5.4 Desuckering

As with vegetative secondary growth, suckers are promoted by the availability of soil moisture. Unwanted suckers should also be removed at intervals of 2 to 4 months to prevent adverse effects similar to those of delayed handling.

#### 7.5.5.5 Handling and desuckering

The combined effects of timely handling and desuckering ('centring'), assist in maintaining an open tree canopy for efficient pest and disease control, air circulation and light penetration for better tree growth, flowering, fruitset and production.

All the above can be referred to as 'maintenance pruning'. It is advisable to maintain well pruned bearing heads for effective application of fungicide sprays.

#### **7.5.6 Change of production cycle**

- **Multiple stem coffee**

In the multiple stem pruning system, the lower branches are removed each year during the main pruning once they have produced a maximum of two crops (two years of cropping). The change of cycle is initiated when the lower branches have been removed up to 1.40m from the ground.



Sufficient bearing heads are removed to leave one or two bearing heads. (Below 2000 trees/ha, leave 1 or 2 bearing heads, above 2000 trees/ha, leave only one). Bearing heads should be removed as close to the stump as possible. Both recycle pruning and stumping are achieved by cutting the stem with a pruning saw at 30-45cm above ground level. The cutting angle should be 45°, sloping away from the centre, to avoid rain water collecting above the cut and causing stump rot.

The bearing heads left on the stump should be strong, high yielding, preferably away from the rising sun, so that they do not cast a shadow over the new suckers. Growing suckers should always be exposed to the sun, to avoid producing weak suckers with long internodes. This is achieved by cutting off any branches on the remaining bearing heads, above the growing points of the new suckers.

In areas of unsatisfactory sucker growth, the top green tip of the remaining stem(s) should be capped at the time of notching to break apical dominance.

When rejuvenating old coffee by recycle pruning, sucker growth can be encouraged by stem notching. Injuring the bark by repeated knocking with the blunt edge of the secateurs is as effective as making a deep cut with a pruning saw. It is also faster and less laborious.

The process of changing the production cycle takes 12 to 24 months to be completed, depending on the growth of the suckers. Under shaded conditions, suckers often grow rapidly, producing long internodes. In this case it would be better to remove the remaining bearing head after 12 months (one cropping season), particularly if the developing suckers are being overshadowed by the bearing head.

In unshaded coffee, where the suckers grow more slowly, with short internodes, the remaining bearing head may be left for 24 months (two cropping seasons) before removal.

- **Single Stem**

Closely-spaced coffee brought up on a single stem system e.g. Catimor and Caturra, should be handled and desuckered as for multiple stem coffee. However, annual removal of the lower branches may not be necessary unless the trees are likely to over-bear.

When changing the production cycle, all branches on one half of the tree, preferably the sunny side, should be removed ('slab pruned'). A notch about 1cm deep at 45cm above ground level, should be made in the trunk, on the

pruned side. At this time, moss should be removed from the stump and the green tip should be capped. The remaining primaries may be thinned out if necessary, particularly in closely spaced coffee. The remaining old head is removed just above the highest sucker, after 2 cropping seasons.

At close spacing, complete stumping by rows or blocks, preferably leaving lung branches, may be more practicable.

- **Single stem capped coffee (umbrella type)**

Although not recommended, much smallholder tall coffee is managed as a single stem capped coffee, on which an 'umbrella' of growth develops around the capped stem. To recycle such coffee, half the umbrella on the side exposed to the sun should be removed. The remaining branches of the umbrella should be thinned out and a notch made on the pruned side of the stem, about 1cm deep at 45cm above ground level. The number of suckers encouraged to develop will depend on the plant density. The remaining old head is eventually removed just above the highest sucker.

- **Stumping**

The change of production cycle can also be achieved by complete stumping, particularly where the coffee is closely spaced. This is an option with multiple and single stem coffee, and is the simultaneous removal of all bearing heads.

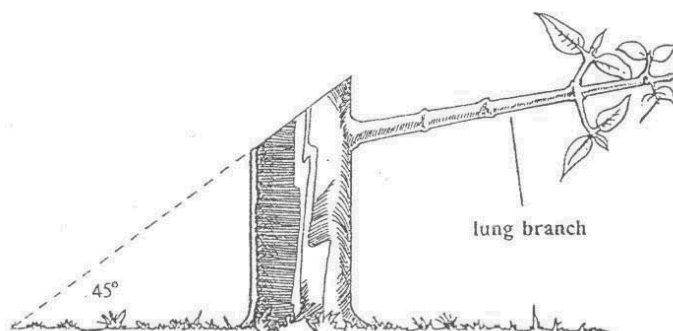
When complete stumping is practiced, care should be taken to leave a lung branch or breather, otherwise the stumps may dry up. A lung branch is the lowest primary and is removed later when the old stump is trimmed just above the highest new sucker.

#### Advantages

- Much stronger suckers are obtained due to the fact that sunlight penetrates to the base of the tree.
- It is simpler and quicker.

#### Disadvantages

- The grower is without a crop for about 2 years.
- Stumps may die.
- More weeding will be necessary



**Figure 7.1: Stumped coffee with a lung branch.**

Stumping is most appropriate in populations greater than 2500 trees/ha. Here stumping can be arranged by rows or blocks on a rotational basis to ensure the grower does not suffer total crop loss. The best approach is to stump approximately 20% of the coffee trees each year.

- **Timing of recycle pruning/ stumping**

The timing of recycle pruning/stumping is based on the production cycle. Normally, coffee yields increase with maturing bearing heads up to a point and then start declining. With experience, a grower will be able to initiate the change of cycle at the right time to maintain regular production.

As with main pruning, the actual recycle pruning/stumping should be undertaken immediately after the main crop is harvested. The length of the production cycle depends on altitude, plant growth, production capacity and the level of management. In general, production cycles of between 4 to 7 years are maintained in different situations. Production cycles tend to be shorter at lower altitudes and longer at high altitudes.

- **Sucker selection**

Many suckers per stump will grow following recycle pruning/stumping and onset of the rains. Sucker selection should therefore be initiated as early as possible and continued on a regular basis. Except for the selected suckers, all the other suckers should be removed with secateurs.

The selected suckers should be strong, healthy and well-spaced around the stem. Two suckers should not be allowed to originate from the same bud, because they are both likely to break off. Initially, more suckers than required

are selected. If three are required, it is safer to start with 5 and reduce them progressively until 3 are left. The final selection should be done at the time of removing the remaining old heads. No suckers should be allowed below 15cm on the main stem, since such suckers are liable to frequent breakages. Ideally suckers should be between 30 and 45cm from the ground and never above 60cm.

Sucker selection should be initiated when the suckers are 10-15cm tall and continued on a regular basis. Unwanted suckers are a drain on plant nutrients.

See Section 7.3.4.6 for foliar fertiliser recommendations.

### **7.5.7 Multiple stem coffee without change of production cycle**

An alternative pruning practice currently in use in PNG (but not yet tested by the CIC RGSD) is multiple stem coffee, on which one upright is removed and replaced each year. Such coffee therefore has uprights of different ages, including a young sucker(s) developing in place of the most recently removed old upright. Uprights only last for three or four years (depending on the number of uprights on each tree).

The advantages of this system are that there is no change of cycle, and therefore no yield loss due to the change of cycle; and yields remain more even over the years. The disadvantages are that, unless carefully managed, young suckers risk being over-shaded by older uprights, which would result in weak uprights with long internodes and therefore less crop; and there is a risk that too many uprights will develop.

## 8.0 DISEASES OF COFFEE

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### 8.1 COFFEE LEAF RUST

#### 8.1.1 Introduction

Coffee leaf rust (CLR) is caused by the fungus *Hemileia vastatrix* Berk and Broome and is the most serious disease of *Coffea arabica* in Papua New Guinea. Since April 1986, CLR has been detected in almost all coffee growing areas of the country. The main damage is due to premature leaf fall, which in most cases results in the trees becoming heavily defoliated. Since leaves carry out photosynthesis (the process by which carbohydrates are formed), defoliation has serious consequences for the coffee trees. It results in inadequate carbohydrate formation, the tree then begins to use carbohydrate reserves in the roots and stems, leading to undernourishment of the tree. Undernourishment results in dying back of the feeder roots which normally carry out the absorption of nutrients from the soil. Similar die-back can be noticed on the branches. Since the coffee tree demands a high carbohydrate supply for successful maturation of the crop, it is evident that CLR has an adverse effect on yield as well.

#### 8.1.2 Symptoms

Infection results in the formation of large yellow-orange, powdery, circular pustules, produced on the underside of leaves. Pustules are at first roughly circular and about 2-4mm in diameter. At a later stage, adjacent pustules may coalesce forming irregular patches larger than 40mm across. The centres of the pustules eventually die, changing to a brownish colour. The pustules can be seen through the upper surface of the leaf but the powdery orange spores (uredospores) are only produced on the underside of leaves.

The presence of only one or two pustules on the leaf is likely to cause premature leaf fall.

#### 8.1.3 Control

The development of CLR resistant varieties is the long term answer to the problem, and since 1992, Catimor variety, a compact rust resistant hybrid, has been available from the CIC RGSD.

However, the majority of plantings are of varieties susceptible to CLR, and adequate rust control can be achieved by the use of appropriate fungicides. Before coffee can be considered for spraying, it must be:

- adequately weeded
- well drained
- in a good physical state showing no nutrient deficiency symptoms
- fenced
- well pruned
- and with no, or correctly maintained, shade.

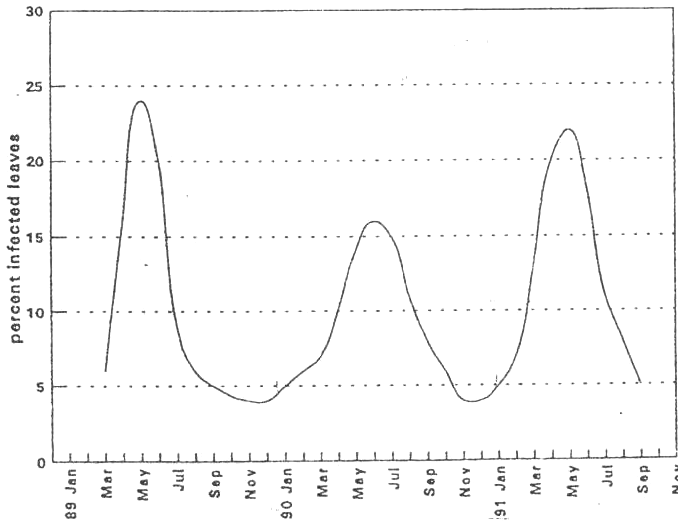
Application of fungicides to coffee which does not comply with the above standards will be less effective than when applied to correctly maintained coffee, and consequently a waste of money. The chemicals (fungicides) used to control CLR can be classified as either protective or systemic.

- Protective fungicides  
These fungicides will prevent the rust spores penetrating the leaf, and should be applied **before** the visible symptoms of the disease. All copper based fungicides belong to this group.
- Systemic fungicides  
These are sometimes called **curative** fungicides. This means that the fungal infections which have already become established can be stopped from developing further. Examples of this group of fungicides are Bayfidan, Tilt and Anvil.

#### 8.1.3.1 Protective spray programmes

Copper fungicides should be applied as a spray to protect the foliage from infection well before the symptoms of the disease are visible. The recommended time and frequency to apply the copper fungicides are detailed in Table 8.1. Studies by CIC recorded seasonal peaks during May-July at Waghi Mek and July-September at Jolamuna. At both sites minimum disease levels were recorded in November-January with inoculum levels increasing steadily from around January-February onwards.

From studies of the seasonal pattern of development of epidemics of CLR and the seasonal periodicity of epidemics, there is only one peak in the CLR epidemic each year (Figure 8.1). At most sites in PNG this peak occurs between May and July, although the precise timing varies with locality and the year.



**Figure 8:1: The seasonal pattern of development of epidemics of CLR between March 1989 and October 1991.**

The severity of CLR epidemics is closely related to both the mean monthly maximum and minimum temperature. Temperatures above 30°C and below 15°C are detrimental to the development of CLR because of their adverse effect on the germination and infection processes.

If no temperature data are available and altitude alone is used, the following modifying effects should be considered.

- Broad valleys in the highlands are often warm for their altitude e.g. Wau, Bena, Asaro, Waghi and Lai Valleys.
- Enclosed basins, narrow timbered valleys, and places with high rainfall tend to be cold for their altitude, e.g. Oksapmin Basin and the Mendi Valley.

An additional benefit in spraying protective copper fungicides is from the copper tonic effect. This promotes leaf retention and results in more nutrients being available for the ripening fruit. However, it should also be noted that incorrectly timed applications of copper fungicides can in some circumstances make the coffee rust worse.

**Table 8.1: Spray programmes for coffee leaf rust**

ALTITUDE OF COFFEE	SPRAY PROGRAMME
Over 1550 m.a.s.l. Annual temperature range. Max. below 25°C Min. below 15°C	One or two copper sprays in January and February.
Below 1550 m.a.s.l. Annual temperature range. Max. above 25°C Min. above 15°C	Two or three copper sprays (the first in October, second in December and the third in February/March).

m.a.s.l. = metres above sea level

Currently recommended rates for copper fungicides are shown in Table 8.2.

**Table 8.2: Recommended rates for copper fungicides**

Fungicides	Rates	Volume per hectare
Champion 50% Cu WP Copper Nordox 50% Cu WP Copper Sandoz 50% Cu WP	Either 3.5g/l or 5-7g/l	700 litres 300 litres
Champion 35% Cu Flowable Kocide50% Cupric Hydroxide	4ml/l 3.5g/l	300 litres 300 litres

### 8.1.3.2 Systemic spray programmes

If CLR has already become established, systemic fungicides should be used to prevent further development of the infection.

Coffee should be monitored regularly throughout the year for CLR, and the level of infection calculated in the following way. Walk diagonally across the coffee block monitoring every tenth tree, ensuring that in small blocks a minimum of 10 trees are monitored. Select four laterals from each tree equidistant between the top and the lowest primary, spaced evenly around the tree. Count the total number of leaves present on the four laterals, then count the number of leaves with orange rust spots (pustules).



The infection level can then be calculated as follows:

$$\frac{\text{Number of leaves with rust spots}}{\text{Total number of leaves}} \times \frac{100}{1} = \% \text{ infection}$$

e.g. Number of leaves with rust spots = 8  
 Total number of leaves = 89  
 $\therefore \% \text{ infection} = \frac{8}{89} \times \frac{100}{1} = 9\%$

Should the level of CLR infection rise to 15% or more around 5 to 6 weeks prior to harvest, a recommended systemic fungicide should be applied.

Currently recommended systemic fungicides are shown in Table 8.3

**Table 8.3: Recommended rates for systemic fungicides**

Fungicide	Rate	Volume per hectare
Bayfidan 25% E.C. (triadimenol)	3.3 ml/l	300 litres
Anvil 5% SC. (hexaconazole)	3.3 ml/l	300 litres

## 8.2 LEAF AND BERRY SPOT

### 8.2.1 Introduction

Brown eye leaf spot is caused by the fungus *Cercospora coffeicola*, Berk and Cooke. This is mainly a disease of plants in the nursery but can also occur in poorly managed mature coffee. The conditions that favour the development of this fungus are high relative humidity and poor nutritional status of the coffee. It also occurs as a secondary infection in physiological die-back.

### 8.2.2 Symptoms

The fungus causes small brown spots on the leaves. The spots usually have a reddish brown margin often surrounded by a slight yellow halo. The centre of the spot turns grey and necrotic, and occasionally may drop, leaving a 'shothole' on the affected leaf.

The fungus can also attack berries, causing small depressed spots, and when this spreads, the whole berry is damaged and may drop to the ground.

### **8.2.3 Control**

In the nursery, spraying with a 0.5% copper fungicide solution at 4-6 week intervals is generally advised to protect the seedlings from severe defoliation and die back.

In the nursery, proper shade management and seedling spacing, and in mature coffee, proper shade management and pruning, allows good air circulation and will minimise the infection. Also adequate nutrition will avoid infection both in the nursery and field.

## **8.3 PINK DISEASE**

### **8.3.1 Introduction**

Pink disease on coffee is caused by *Phanerochaete salmonicolor* (Berk and Broome) Julich, formerly called *Corticium salmonicolor* Berk and Broome. This fungus is widely distributed and recorded on many other tropical crops such as rubber, cacao, citrus, tea, some food crops and ornamentals in Papua New Guinea. Wet, humid conditions favour the development of the fungus, and an extended period of dry weather may slow down the infection, and the infected stem may recover.

### **8.3.2 Symptoms**

On coffee, the fungal mycelium is at first superficial i.e. on the surface, and appears as fine white threads on stems, branches or berries. The affected young green twigs can later become dark brown and die. When the older stems are infected, the mycelial threads change into a pink crust and the fungus enters the cambium, killing it. This crust develops on the underside of branches. When the infection surrounds the whole stem or branch, the upper parts die due to interruption of the normal nutrient translocation.

If the growth of the pink crust is halted, the bark may often crack and lift, causing it to flake off and expose the hard wood underneath. Around the edge of the bare wood the bark forms callus tissue which can sometimes be so extensive as to ring-bark a stem.

Occasionally the asexual stage of the fungus occurs on the upper surface of branches as orange-red cushion-like structures. The role of this stage of the fungal life cycle in the spread of the disease is unknown.

### **8.3.3 Control**

The disease can be controlled by either cultural or chemical methods. Heavy shade, and/or unpruned coffee, tends to maintain high humidity in wet seasons, favouring fungus development. Correct shade density and pruning will minimise disease infection and development.

Infected laterals should be cut out and burned on site, or placed in a large plastic bag and removed from the coffee to be destroyed elsewhere. Any infection on the uprights should be cleaned and treated with copper paste (mix just enough water with copper powder to make it sticky). Where the infection has reached an advanced stage, it may be advisable to stump the tree and burn all the infected branches.

Pink disease also lives on, and attacks, a wide range of other plants, e.g. cacao, rubber, citrus, tea and many ornamental and shade plants. Therefore, it is essential to pay attention to all other plants grown in and around coffee. Should these plants be infected with Pink disease, they must be treated and/or removed from the coffee.

Chemical control can be effected by spraying with Bordeaux mixture (1kg copper sulphate, 1kg hydrated lime and 100 litres of water), or painting the affected areas with Calixin fungicide. In circumstances where the crop is heavily infected with Pink disease, Bayfidan at the rates recommended for coffee leaf rust will control the disease. The effects of Bafidan application will become evident after 56 days. For serious infection of Pinks disease Baifidan should be applied in October, December and February.

## **8.4 BLACK ROT**

### **8.4.1 Introduction**

Black rot is caused by *Koleroga noxia* Donx, and is sometimes referred to as Tawny Thread Blight. The disease is favoured by warm, moist conditions, so it is most common in lowland areas. In highland areas it is rarely of economic significance.

### **8.4.2 Symptoms**

The fungus grows on the under-side of coffee leaves as a silvery web and later spreads to the petiole and then down the stem. The affected petiole dies and the leaf is detached, eventually turning black. Usually leaves remain hanging

to the branch by brown fungal threads. The green twigs and berries can also be affected.

#### **8.4.3 Control**

The disease is best controlled by proper shade management and by cutting out and burning infected branches on site. Chemical control is usually not an economical proposition, although a 0.5% copper fungicide may be considered.

### **8.5 WHITE THREAD BLIGHT**

#### **8.5.1 Introduction**

The disease is caused by species of *Marasmius* and *Corticium*, and although not a serious disease could be a problem in high rainfall areas.

#### **8.5.2 Symptoms**

The white strands of mycelium, known as rhizomorphs, spread from the stems onto the under-side of the leaves. The affected leaves dry up and become detached, however, they do not fall off because they are held by the white fungal mycelial strands.

#### **8.5.3 Control**

It can be controlled by reducing humidity by careful thinning of shade, proper pruning and by cutting out infected branches and burning them on site.

### **8.6 SECONDARY INFECTIONS ASSOCIATED WITH DIE-BACK**

#### **8.6.1 Introduction**

When the coffee tree is carrying an unusually heavy crop, but for various reasons is receiving inadequate nutrition, overbearing die-back can occur. Some reasons for inadequate nutrition are incorrect crop estimation and consequently insufficient fertiliser being applied; waterlogging, when the roots cannot absorb sufficient nutrients; and removal of shade trees without adequate fertiliser application (refer to Section 7.3, for correct fertiliser rates).

Under these conditions the berries are often infected by three fungi, namely, *Colletotrichum gloeosporioides* (Penz) Penz and Sacc., *Cercospora coffeicola* Berk. and Cooke and *Fusarium* sp.

These fungi are not the primary cause of die-back, but are secondary invaders which aggravate the situation.

### **8.6.2 Symptoms**

Twigs and branches die back from the tips and considerable defoliation occurs. The secondary invading fungi cause brown-black sunken spots on mature berries and occasionally on green immature ones. In a more advanced stage on the affected branches, the berries die and fall to the ground.

### **8.6.3 Control**

An appropriate balance of shade and fertiliser application and crop regulation by stripping if necessary, will control die-back and therefore avoid secondary infection.

However, should any secondary infection occur, it can be controlled by normal coffee leaf rust fungicides.

## **8.7 STEM CANKER**

### **8.7.1 Introduction**

The disease is caused by *Fusarium* sp., and it has been observed that waterlogging favours the infection.

### **8.7.2 Symptoms**

The fungus usually infects the bark at ground level (collar) and grows in the bark around the stem. The symptoms seen in a more advanced stage are general leaf yellowing followed by wilting and eventual death. The infection site is usually constricted and the bark above the constriction is usually soft and spongy. The region under the infected bark is reddish brown to purple when cut.

### **8.7.3 Control**

Young seedlings should not be planted too deeply, in order to avoid soil contacting the bark of the stem, as this minimises the incidence of the disease. The bark at ground level should be kept free from excess moisture by providing good drainage, and affected dead plants should be uprooted and burned on site to reduce the inoculum for further infections.

## **8.8 ROOT DISEASE**

### **8.8.1 Introduction**

Root rot is not considered to be a serious problem in coffee in Papua New Guinea.

When it occurs it may be caused by one of a number of different fungi including *Phellinus noxius* (*Brown Root Rot*), *Rosellinia* sp., (*Black Root Rot*), *Fomes lignosus* (*Red Root Rot*), *Fusarium* sp. as well as a number of other fungi.

### **8.8.2 Symptoms**

General yellowing and wilting of foliage of the whole tree. Brown, black or red fungi mycelium or staining of woody tissue below the bark may be evident, giving an indication of the causal fungus. Occasionally fungal fruit bodies may be present in the collar region of the trunk from which a definitive identification may be made.

In all cases wilting and yellowing of the foliage is accompanied by a decay of the roots.

### **8.8.3 Controls**

Once a tree has become infected it cannot usually be saved and must be dug out along with its diseased roots to prevent root to root infection between adjacent trees. Sometimes it may be necessary to dig a trench around the diseased tree and its immediate (apparently healthy) neighbours to contain the disease by eliminating root contact between these and other trees.

Once an infected tree has been removed it should be burned if possible. Because the pathogen can remain infectious on decaying roots which have not been removed from the soil, infilling should be delayed for at least two seasons to allow complete decay of diseased roots and consequent death of the pathogen.

## **8.9 LIGHTNING STRIKE**

### **8.9.1 Introduction**

Lightning strike is quite common on coffee and other trees throughout Papua New Guinea. Whilst not a disease it is frequently mistaken for one and diagnosis can be complicated by the invasion of dead and dying trees by saprophytic fungi if trees are not examined as soon as possible after the lightning strike.

### **8.9.2 Symptoms**

A ring of trees around the centre of the lightning strike will be affected.

Trees in the centre of the group appear to collapse and die very quickly whilst foliage of surrounding trees, particularly in the crown area, wilts, becomes brown and the affected branches die. Symptoms become less pronounced moving away from the centre of the strike.

### **8.9.3 Control**

No control is possible but it is useful to be aware of the condition and to be able to distinguish it from the diseases with which it may sometimes be confused.





## 9.0 PESTS OF COFFEE

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### 9.1 SCALE INSECTS

#### 9.1.1 Introduction

Green scales *Coccus* spp., (Hemiptera: Coccidae) are scale insects that feed on coffee and other plants in Papua New Guinea. The scales are widely distributed and occur in most coffee growing areas, attacking both Arabica and Robusta coffee. Ants are always associated with them because they feed on the honeydew excreted by the scales. Two species, *C. celatus* De Lotto and *C. viridis*, are present, but identification in the field is difficult and must be carried out by a specialist. Both species occur together in most locations. Scales are attacked by Coccinellid beetles, fungi, and parasitic wasps native to PNG, but seldom severely enough to limit heavy scale infestations.

#### 9.1.2 Description and damage

The adult females are oval shaped, fairly flat, and pale green in colour, with a soft skin, varying in size up to 4mm long and 2mm wide. *C. viridis* is pale green in colour while *C. celatus* is myrtle (dark) green in colour. Males have never been recorded and the genus reproduces asexually (parthenogenetic). It takes one to several months for the scale to complete its life cycle. The adults are most abundant during October to January in the Eastern Highlands, however this may vary slightly for other regions. Generally, green scales favour young coffee, new shoots and the lower habitat of the coffee bush. There are many alternative hosts for green scales, of which citrus is the most important.

Both adult and young (crawlers) suck the sap, and the adults become firmly attached to the plants. The scales excrete honeydew on the leaves and branches, which provides food for a group of fungi called 'sooty mould' to grow on. In mature plants, the scales and the sooty mould affect the number of fruiting nodes per branch per tree, one of the components of yield in coffee. Where there are severe infestation levels (defined as green scale and sooty mould seen on the primary branches in the top, medium and low canopy of bearing coffee bushes) in the field during flowering, there is a loss of 21% of flowers, and subsequently a loss of 16% of fruiting nodes. The overall effect would be a loss of about 50% of cherry. However, reduced growth and death are common in young plants with heavy infestation.

There are at least 4 species of ants that attend the green scale. The commonest is *Pheidole* spp., which is about 2-4mm long, with a black head and abdomen, and a red-brown thorax. Yellow Crazy ants (*Anoplolepis gracilipes*)

can be found in the warm highland areas, and can displace *Pheidole spp.* Small Black ants (*Crematogaster spp.*), Weaver ant (*Oecophylla samardgina*) and Tropical Red Fire ant (*Solenopsis germinata*) are widespread on Robusta coffee in the lowlands. The green scales benefit from the ant tending through the removal of honeydew, protection from natural enemies, transportation to more favourable sites, and construction of mud shelters.

### 9.1.3 Control

- **Chemical control**

Ants : Dieldrin has been used in the past to control ants, but it is now banned due to its toxicity and persistence. The following chemicals have been recommended in other countries for the control of ants but could also be used in PNG. Infested coffee should be treated with Dursban EC, Losban EC, Cislin 25, Bifenthrin EC, or Amdro bait (0.2% hydramethylnon). Two applications should be applied before and after flowering between September and December, at the concentrations shown in Table 9.1 (a).

The trunks of infested bushes should be sprayed with insecticide from ground level to a height of about 50cm. This should keep the ant population at low levels for 2-3 months to allow effective parasitism of the green scale by the parasitic wasps (see Biological control). Amdro can be applied directly on the ground near green scale infested trees. Ant control should be seen as the best long term measure for green scale control.

Green scale : White Oil alone can be used on young crawlers during the dry season months of March to June. The number of applications depends on the severity of infestation. It can also be mixed with a low concentration of Malathion 500EC to achieve control, using three applications at monthly intervals between August and October.

**Table 9.1 (a): Pesticides for the control of ants**

Pesticide name	Active Ingredient	Amount to mix with 200 litres water to treat one ha of infected coffee	Method of Application
Dursban or Lorsban	Chlorpyrifos 500 EC	800 ml	Spray on base of infected tree and on trunks and branches. Two applications, applied before and after flowering between Sept. and Dec.
Cislin 25	Deltamethrin 2.5 EC	3.75 litres	Spray on the base of infected tree and on trunks and

			branches. Two applications, applied before and after flowering between Sept. and Dec.
Bifenthrin	Bifenthrin 100g/litre	2 litres	Spray on the base of infected tree and on trunks and branches. Two applications, applied before and after flowering between Sept. and Dec
Amdro bait	Hydramethynon 0.2 %	2.5 kg	Spread the bait around the base of infected tree. Two applications, applied before and after flowering between Sept. and Dec.

From September to December, **only** coffee bushes that are **severely** affected by green scale should receive foliar application of higher concentrations of the insecticides. Severe infestation is defined as the presence of green scale on the top, middle and lower canopy of the tree. The insecticides can be applied at the rates shown in Table 9.1 (b) using either a knapsack or a mist blower, targeting the spray to the lower canopy and working up the coffee bush.

**Table 9.1 (b): Pesticides for the control of green scale**

Pesticide Name	Active Ingredient	Amount to mix with 200 litres water to treat one ha of infected coffee	Method of Application
White Oil	White oil	2 litres	Spray foliage and branches of infected trees. Number of sprays depends on severity of infestation. Usually applied to mature coffee trees in the dry season – Mar –June
Malathion and White Oil mix	Malathion 500 EC	700 ml Malathion 2 litres White Oil	Spray foliage and branches of infected trees. Apply 3 times at monthly intervals : Aug. - Oct.
Dursban or Lorsban	Chlorpyrifos 500 EC	800 ml	Spray foliage and branches of infected trees. Apply 3 times at 14 day intervals between Aug. and Sept. before flowering
Mospilan	Acetamiprid 20% SP	400 g	Spray foliage and branches of infected trees. Apply twice in Sep. at 14 day intervals
Confidor	Imidacloprid 200 EC	800 ml	Spray foliage and branches of infected trees. Apply once in October

- **Biological control**

One introduced parasitic wasp, *Metaphycus baruensis* Noyes (Hymenoptera: Encyrtidae), has been released, and has established in many areas of the coffee growing regions. The parasitism level recorded was up to 80% in the absence of ants. Field parasitism has been very variable when ants are present. The parasite has been seen to increase during months when the adult green scales are most abundant. Other control agents include Coccinellid beetles, an entomophagous fungus (*Verticillium lecanii*) (see Table 9.1 (c)), and a native wasp in the genus *Cheiloneurus nr chlorodryini*. A biological pesticide is currently being tested and is showing early positive results.

**Table 9.1 (c): Biological control of green scale**

Biological Control pesticide	Active Concentration	Amount to mix with 200 litres water to treat one hectare of infected coffee	Method of Application
<i>Verticillium lecanii</i> mixed with glycerol	<i>Verticillium</i> spores at $1.6 \times 10^7$ spores/ml in 0.1% glycerol.	$3.2 \times 10^{12}$ spores and 40 ml glycerol	Spray foliage and branches of infected trees. Two monthly applications in October and November. For best results, apply <i>Verticillium</i> after single application of Chlorpyrifos, Confidor or Mospilan.

- **Cultural**

Maintenance pruning or handling which serves as a hygienic cultural method can be employed according to an individual garden's field programme to reduce the green scale population. This should be targeted on unwanted secondary branches and shoots, mainly in the lower canopy of the coffee bushes, where most of the scale population are found. This cultural control method can best be employed during the months of November to December, the period of peak adult scale population generally observed in most sites.

- **Integrated Pest Management (IPM)**

More effective control can be achieved using a combination of chemical, biological and cultural control methods.

## 9.2 COFFEE BERRY BORER

### 9.2.1 The Pest

The Coffee Berry Borer (CBB), *Hypothenemus hampei* Ferrari (Coleoptera: Scolytidae), is a small black beetle 1.5-1.8 mm long. The female beetle bores into young and ripe coffee berries, generally through the navel (tip) region. The adult female lays between 30-120 eggs (average 50) in the tunnel bored into individual mature coffee beans. The grubs (larvae) feed on the bean, making small holes. Complete development from egg to adult takes about 25 to 35 days. All life stages can be found within the coffee bean. The juvenile stages last for 4 (eggs), 15 (larva) and 7 (pupa) days, respectively at 27°C. Mating normally takes place inside the berries and the female is capable of laying eggs in 3-4 days after emergence. On average, the fertilised female lives up to 157 days and seeks out other fresh berries for oviposition. Males may live for 20 to 28 days. In one year, up to 9 generations of CBB are produced, giving rise to a massive buildup of progeny, depending on the climate and availability of coffee cherries.

CBB is found in all coffee-growing regions of the world. It was first recorded in Gabon in 1901, and since then has spread to many parts of Africa, South America, Central America and South-East Asia. It is not yet in PNG, but the presence of CBB in Wamena and Oksibil districts of Papua province in Indonesia, and in New Caledonia, is a serious threat to the coffee industry of PNG.

### 9.2.2 Damage and crop loss

The pest is monophagous, feeding exclusively on immature and mature coffee cherries, and not damaging the vegetative parts of the plant. The damage to the bean is caused by adults tunneling into the distal end of cherries to lay eggs and the grub (or larva) tunneling around the hardened beans inside the cherries to feed.

The female adult tunnels into green cherries about 8 weeks after flowering. It stays inside the tunnel, until the bean hardens, to lay eggs.

Crop losses are due to damage to the beans caused by CBB during its breeding cycle in both young and older cherries. Considerable loss can be caused by attacks on the young cherries, which fall to the ground following boring. It may continue in ripe and over-ripe cherries on the tree or on the ground. In case of severe infestation, 30-80% of the cherries may be attacked, resulting in heavy crop loss.

Market quality requirements demand the removal of damaged beans from the harvested crops, and if the beans are further sorted, they are relegated to the low-grade category.

If bean drying and storage conditions are not followed correctly, CBB can breed on Arabica beans with moisture content above 13.5% and in Robusta beans above 12.5%.

### **9.2.3 Host range**

*H. hampei* is monophagous and lives and breeds only in *Coffea* species. The two most widely grown species, *C. arabica* (Arabica) and *C. canephora* (Robusta), are both susceptible to CBB. Other species are also attacked, but *C. liberica* has shown resistance to CBB.

The pest is known to use other plant species for feeding only, including Tephrosia, Crotalaria, Centrosema, Caesalpinia, Leucaena, Hibiscus, Rubus, Vitis, Ligustrum, Oxycanthus and Phaseolus. However, these plants cannot support the life cycle of the insect.

*Hampei* eggs have been found in a legume, *Dialium lacourtiana*, but completion of the life cycle in the bean has not been demonstrated.

### **9.2.4 Ecological and cultural factors affecting development and spread**

The seriousness of CBB is influenced by the altitude, prevailing temperature, rainfall and the cultural conditions.

#### **9.2.4.1 Altitude**

*H. hampei* is a serious pest of both low and high altitude coffee. It has been found to survive above 1,900 masl, and is thriving on Arabica coffee at Wamena and Oksibil in Papua province, Indonesia at 1,700 and 1,750 masl respectively. In PNG coffee production is concentrated between 1,200 to 1,600 masl.

#### **9.2.4.2 Climate**

The development of various stages of the pest's life cycle is dependent on the local conditions, particularly temperature, as influenced mainly by altitude. For example in Mexico, the pest is most abundant between 500 and 1000 masl, corresponding to average temperatures of 23-25 °C.

Rainfall has little direct effect on CBB incidence, however where infested cherries have fallen to the ground and become dry, renewed wetting through rain stimulates the release of female borers.

Rainfall has a considerable indirect effect on CBB through its influence on flowering and cherry development. The availability of cherry all year round (as in PNG) provides food and breeding opportunities, resulting in the presence of the insect throughout the year. Infestations can therefore be continuously high, with up nine generations a year depending on climate and cultural conditions. The generations may overlap, with various stages of insect being present at any one time.

#### 9.2.4.3 Cultural conditions

Infestation of CBB is favored by:

- heavy shade, even a single, very large, dense shade tree can cause a serious local infestation;
- close planting;
- un-pruned trees;
- continuous flowering; and
- fallen cherries on the ground.

Infestation is greater in damp, shaded plantings than dry, open areas. These conditions correspond to the smallholder production system in PNG, which therefore provides the best environment for CBB to thrive and flourish.

Inefficient pruning not only creates the humid conditions favored by the pests but also creates a situation where many cherries are too high to reach during harvesting. These are therefore left behind, providing a food source for CBB.

#### 9.2.5 Dispersal

Most females fly from infested cherries during mid to late afternoon to seek out new cherries to infest. They may also be exploiting periods of maximum heat convection in the atmosphere, which facilitate long-distance travel.

In free flight, beetles can fly for up to 22 minutes, tending to hover or move forward only slowly. When wind assisted and in dry conditions they frequently fly non-stop for 100 minutes. Flights of up to 345 minutes have been recorded.

Longer distance travel is probably brought about in numerous ways:

- Inter-country travel is more likely through human associated activities than in air currents;

- Infested beans are an obvious and recorded dispersal mechanism;
- Adults present in materials used for packing, or having bored into logs;
- In sacks which have contained infested beans;
- On clothing of coffee cherry pickers or other workers;
- Occurrence in imports of pods or seeds of non-Coffea species for purposes other than coffee cultivation, e.g. legume cover crop seed.

## **9.2.6 Control measures**

### 9.2.6.1 Sanitation

The average female CBB life span is 157 days. This means that the borer can survive from one crop to the next even in countries where trees only produce a single crop each year.

In the absence of chemical means, the only way to break the pest cycle is, therefore, to remove every potential breeding site. This requires that:

- Harvesting is complete;
- All remaining cherries, both on the tree and on the ground floor, are collected and destroyed;
- Removal of young cherries on which all adult females might feed;
- Removing off-season flowers.

### 9.2.6.2 Host Plant Resistance

Only *C. liberica* is practically resistant to CBB.

This coffee species could be used as a barrier crop in the overall management of CBB.

### 9.2.6.3 Chemical control

Confidor (Imidacloprid) has been shown to provide effective in control when sprayed at the same rate as recommended for Green Scale..

### 9.2.6.4 Biological control

To achieve greater control, biological control can be used as part of an integrated programme of pest management.

A number of natural enemies of CBB exist including *Cephalonomia stephanoderis*, *Prorops nasutu*, *Phymastichus coffea* and *Beuveria bassiana*. The first two parasitoids enter tunnels made by CBB and lays eggs on the larvae and pre-pupae. The emerging parasitoid larvae feed on the borer stages



and kill them. The adult parasitoid also feeds on all life stages of CBB. *P. coffea* parasitoid lays eggs on borer beetles when it enters the berry.

The White Muscardine fungus, *B. bassiana*, infects and kills the beetle under favorable environmental conditions of high humidity (relative humidity above 80%) and optimum temperature between 25-30°C.

### **9.3 COFFEE RING BORER**

#### **9.3.1 Introduction**

The coffee ring borer *Meroleptus cinctor* Marshall (Coleoptera: Curculionidae) is a weevil that is common in coffee plantations in the highlands. Its common host is sweet potato but it also attacks coffee in nurseries and field plantings; hence it is likely to be a more severe problem on smallholder coffee than on plantations.

#### **9.3.2 Description and damage**

The adult weevil is brown to black in colour depending on age, and approximately 7mm in length. If disturbed, it will pretend to be dead. The short, flat, off-white larva has a dark head, while the pupae are off-white, turning brown before emergence.

The larvae feed on the inner bark and the outer layer of wood, forming a tunnel, usually horizontal, around the trunk. Severity depends on the age of the tree. In larger trees, wounds heal quickly, but in young trees, wilting occurs above the horizontal ring causing new shoots to develop from below. If the trunk is more than 20cm in diameter, damage is usually repaired progressively and wilting is often less severe. General yellowing, hastened fall of leaves and symptoms of 'die back' occur after wilting. The effects on young trees are generally delayed cropping and increase in yield the following year, if there is not a repeat attack.

#### **9.3.3 Control**

Sweet potato should be cleared from prospective coffee planting areas. Where incidence is high, the coffee uprights should be cut off and burnt. Chemical control by foliar spray is generally not successful but Lorsban 0.5% applied with a brush to the main stems of all bushes to a height of about one metre, or where the bark becomes smooth, will give adequate control.

## 9.4 LEAFHOPPERS

### 9.4.1 Introduction

Leafhoppers are plant insects (Hemiptera: Cicadellidae). Eight species of various families are common inhabitants of coffee but are not economically important. Two species in the genus *Batrachomorphus* have so far been reported to occur in medium to dense populations on coffee in the Morobe (Wau), Eastern Highlands, Western Highlands and Enga Provinces (Tsak Valley). These are *B. szentivanyi* Ghauri and *B. blotei* Ghauri. A new genus *Archeguina*, has been described with 5 new species, mainly from the high altitude areas of PNG.

### 9.4.2 Description and damage

These insects have two pairs of wings, and sucking mouth parts, feeding mainly on plant sap (phloem). Any soft plant part may be pierced for ingestion of sap. The general outline of their body is small, long and slender. The adult female is brown, and the male varies from dark bluish colour to dark green. Male and female can be told apart by the egg laying tube on the female abdomen. Female leafhoppers lay their eggs embedded in soft internodes of primary or secondary branches of coffee. The eggs hatch into wingless but very active nymphs, black at first but changing to green at a later stage, which also feed by sucking. The nymphs develop to adults, changing their skin several times during the process. This is reported to take about 4 months. The insect is reported to appear during the middle months, and to remain until the later months, of the year, but this depends on locality. There is an overlap of developmental time due to the presence of different stages, however, populations are usually in 'single phase'.

Generally leafhoppers are known to be occasional pests, but they can be found in medium to dense populations. Where this insect is abundant in any crop, the plant shows a lack of vigour, retarded growth and in most cases yellowing of leaves. There is also warping of wood as a result of egg laying. Some species are virus vectors, for instance *Nilaparvata lugens* causing 'hopperburn' in rice, and *Graminella nigrifrons* (Forbes) causing dwarfing in maize.

### 9.4.3 Control

Several natural enemies attack the eggs, nymphs and adults. Eggs are attacked by a parasitic wasp and up to 50% parasitism has been recorded. Nymphs are attacked by a *Dryanid* wasp, the wasp larva developing externally on the leafhopper nymph; while adults are killed by an entomophagous fungus,

normally prevalent when populations are high. Various predacious insects kill both nymphs and adults by sucking body fluids.

Chemical control can be achieved by applying either Basudin, Actellic 50 EC, or Orthene 75. Foliar spray application is advisable if heavy populations consisting of equal numbers of nymphs and adults develop on extensive areas in a coffee block.

**Table 9.2: Pesticides for the control of leafhoppers**

Pesticide name	Active ingredient	Amount to mix with 200 litres of water to treat 1 hectare of coffee	Active product in spray mix
Basudin	Diazinon	500 ml	0.25%
Actellic 50 EC	Pirimiphos-methyl	500 ml	0.25%
Orthene 75	Acephate	330 g	0.25%

## 9.5 COFFEE CENTRE BORER

### 9.5.1 Introduction

The Coffee Centre Borer *Zeuzera coffeae* (Lepidoptera: Cossidae) is a moth that attacks coffee in most coffee growing areas of PNG. Other plants attacked include citrus, cocoa, tea, kapok and various ornamental trees and shrubs.

### 9.5.2 Description and damage

The adult moth is grey or white with many small black dots or marks on the wings and body. The female is larger, with a wingspan of about 5cm, whereas the male's is only 4cm. The adults fly to lights at night and are easily caught in light traps. Eggs are laid singly in crevices and young larvae bore into wood after hatching. The larvae are stout bodied and reddish in colour with a black head, making cylindrical tunnels along the branches. Reddish brown frass (mostly faeces) is extruded from the holes on the surface. Pupation occurs inside the tunnel and adults emerge and fly out through the exit holes. Attacked branches are usually killed.

### 9.5.3 Control

When the population of the Centre Borer begins to rise, parasitic wasps can often control the levels of infestation. Various predacious insects kill both nymphs and adults by sucking body fluids.

Infested branches should be pruned and burnt.

## **9.6 COFFEE LEAF ROLLER**

### **9.6.1 Introduction**

The coffee leaf roller *Hamona coffearia* Nietn. (Lepidoptera: Tortricidae) is a moth distributed widely throughout the coffee growing areas. Alternative host plants include *Crotalaria*, *Dahlia*, *Albizzia stipulata*, wild hops and silky oak.

### **9.6.2 Description and damage**

The female moth is pale brown in colour, with relatively broad wings. The male has darker brown markings with a distinctive upturned margin on the inner parts of the forward edge of the forewing. Eggs are laid in scale-like masses of 20-40 in rolled leaves. The larvae, after hatching, search and feed on soft leaf tissue.

The larvae are dull green to bluish green in colour, with a dark head. They are active and will wriggle if touched. The pupae are usually present in the leaf. The life cycle takes about 8 weeks. Bushes are defoliated to a varying degree and up to 80% leaf loss has been recorded in a single attack.

### **9.6.3 Control**

Various parasites have been recorded attacking larvae, with up to 60% parasitism. Control measures are rarely required, but if necessary Orthene or Karate 75 will give adequate control. The amount to mix per hectare is 330g in 200 litres of water, applied to the leaves. This would give 0.25% active product in the spray mix. To achieve good results, the chemical spray is best applied when the insect population is at the larval stage.

## **9.7 CICADAS**

### **9.7.1 Introduction**

Cicadas (Homoptera: Cicadidae) have been present in PNG coffee for some time, but only occasionally do they become a problem. Little is yet known about this pest or methods to control it. Four species have been found to attack coffee plants, but they have not yet been scientifically identified. It is thought that cicadas have become a pest due to the removal of shade trees and the associated litter layer; by the removal of general predators through loss of the litter layer; and through the use of insecticides to control other pests.

### **9.7.2 Description and damage**

The adults are rarely seen, but their very shrill, high pitched call can often be heard during the day, particularly towards dusk.

The first signs of damage are usually roughness and punctures about 15-20 cm from the tip of young primaries. This may be so severe that the primary breaks at this point and hangs down. The damage is caused by female cicadas laying their eggs in the primaries, usually during February and March.

After several weeks the eggs hatch and the ant-like nymphs fall to the ground, where they enter the soil through cracks. The pest is most vulnerable to predators at this stage, and may also be unable to reach the soil if there is a good layer of leaf litter.

Once in the soil, the nymphs excavate a small cell around feeder rootlets, from which they suck the sap. In general, high populations of the nymphs are found about 15cm below, and 50cm away from, the coffee trunk. If present in large numbers, they can seriously diminish nutrient uptake and the vigour of the tree, causing symptoms very similar to overbearing dieback.

The nymphs remain in the soil for at least one year, but some can spend up to 17 years underground, as in the case of an American species. Once they are fully grown they burrow to the surface, emerging in large numbers at the same time. They crawl up the trunk of the coffee tree, where they rest and emerge as adults. The discarded skin (exuviate) of fully grown nymphs can be seen still clinging to the tree.

### **9.6.3 Control**

No effective and economic methods of chemical control have yet been proven.

Two fungi, *Cordiceps* species, and *Metarrhizium* species, have been found to infest the adults and the nymphs. A larva of a beetle in the family Rhipiphoridae is a predator of the late stage nymph of cicada. Ants are also very important natural enemies of the cicada nymphs.

As a long term control measure, it is advisable to plant shade trees to provide leaf litter, which inevitably will have many other positive effects.

## **9.8 ARMY WORMS**

### **9.8.1 Introduction**

Army worm, *Spodoptera exempta* (Lepidoptera: Noctuidae) is a moth. It is a seasonal pest of coffee, but it is also a pest on leguminous plants, cocoa,

*Gramineae*, a few fruit trees, and some root and vegetable crops. Primary (from low parent population), secondary (from previous outbreaks) or critical (leading to subsequent outbreaks) outbreaks do occur in localities where there is a distinctive dry period followed by some critical rainstorm days.

### **9.8.2 Description and damage**

The adult moth has a robust light brown body, 40mm long. The larva is about 40mm in length, with a soft and often brightly coloured body. A creamy yellowish stripe on both sides of the larva extends from the head to the tail.

The adult females lay eggs either singly or in batches on the host plant. The growing larvae start feeding on the foliage. Several weeks later the final stage larvae descend to the base of the tree, burrow to a depth of 5-6cm, create a cavity resembling a cocoon, and pupate. After several days the adult moth breaks open its casing, emerges and flies away. It takes 21-30 days to complete the life cycle.

A larval density in the range of 16-25/tree is capable of causing considerable defoliation, particularly if there are many immature cherries on the tree. Furthermore the larvae also feed on the expanding cherry, which can be a serious problem.

### **9.8.3 Control**

Field monitoring, to detect the presence of feeding larvae, is essential to ensure timely spray application. Chemical control can be achieved by applying either Orthene 75 or Maldison 500, or both pesticides used in rotation. Foliar spray application is advisable if most of the population is at the larval stage. To achieve good results, a second application using a different chemical may be necessary if the larvae are still observed on the foliage.

**Table 9.3: Pesticides for the control of army worms**

Pesticide name	Active ingredient	Amount to mix with 200 litres of water to treat 1 hectare of coffee	Active product in spray mix
Orthene 75	Acephate	330g	0.25%
Maldison 500	Malathion	500ml	0.25%

## 9.9 SHOT HOLE WEEVIL

### 9.9.1 Introduction

Shot hole weevil, *Oribius* spp., (Coleoptera:Curculionidae) is found in most coffee growing regions, but appears to cause insignificant damage.

### 9.9.2 Description and damage

The adults are dark brown, dark grey or black in colour and about 5mm in size. They feed mainly on the leaves causing many small holes scattered over the leaf surface, so that it looks as if a shot gun has been fired at it.

### 9.9.3 Control

Often the damage is not serious and no control measures are required. Weed control is necessary to minimise the adult population, as many weed species are the main host.

Chemical control should not be used unless absolutely necessary and only in cases of severe weevil attack. Insecticides such as Dursban, Chlopyrifos EC 500, Malathion 500 EC and Imidacloprid 200 EC can provide adequate control. Biological control agents include the fungus *Beauveria bassiana*.

**Table 9.4: Biological control of shot hole weevil**

Biological Control pesticide	Active Concentration	Amount to mix with 200 litres water to treat one ha of affected coffee	Method of Application
<i>Beauveria Bassiana</i> mixed with glycerol	Verticillium spores $1.0 \times 10^7$ spores/ml in 0.1% glycerol.	$2 \times 10^{12}$ spores and 40 ml glycerol	Using knapsack spray on the foliage, branches and on base of infected trees. Use 2 monthly applications in Oct and Nov. for best results.

**Table 9.5: Pesticides for the control of shot hole weevil**

Pesticide	Active Ingredient	Amount to mix with 200 lt of water to treat one ha of affected coffee	Method of Application
Dursban or Losban	Chlorpyrifos 500 EC	600 ml	Using knapsack spray on the foliage and branches of infected trees.
Malathion and white oil mix	Malathion 500 EC	500 ml Malathion 2 litres white oil	Using knapsack spray on the foliage and branches of infected trees.
Confidor	Imidacloprid 200 EC	600 ml	Using knapsack spray on the foliage and branches of infected trees.
Mospilan	20% SP Acetamiprid	300 g	Using knapsack spray on the foliage and branches of infected trees.



## 10.0 HARVESTING AND PROCESSING

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### 10.1 HARVESTING

In Papua New Guinea, the peak of the crop normally ripens in May, June and July, but there is usually enough cherry ripening to extend the season from March to October with what is known as 'fly pickings'. Hand picking should encourage individual cherry selection which is of vital importance. Only uniform red ripe cherries can produce good quality coffee. Picking unripe or green cherry is a waste, because it comes out as reject or Y3 grade green bean, which has to be picked or graded out of the product at some expense. Even pale or under-ripe cherry will still not pulp, because the mucilage has not yet broken down and is still hard. The under-ripe material that does go through to green bean, downgrades the quality of the crop by introducing raw, green or grassy off-flavours.

Overripe cherry (dark red turning to black) will also be difficult to pulp efficiently because the slippery mucilage has now dried up, and the parchment will be badly discoloured. Mixed pickings, containing under-ripe and overripe cherry, ferment unevenly and may also cause bad flavours and taints.

Under conditions of water stress, cherry is likely to be yellow and will produce 'lights' (floater) coffee of poor quality. Cherry picked from over-bearing trees, especially when leading to die-back, will also be yellow-brown and of inferior quality. Cherry picked from trees under severe stress should not be mixed with cherry from healthy trees.

**It must be remembered at all times, that final bean quality cannot be improved upon once the cherry has been picked. It is essential therefore, that a very high standard of picking is maintained.**

As it is normal to have several flowerings in the course of the year, this results in an extended picking season. However, there is always a 'flush' period in any one area, when picking must be carried out every 10-14 days.

Picking is done by hand, the coffee is normally placed into buckets or bags, and payment made at the prevailing agreed rate in the area. Pickers need to be disciplined and prevented from causing damage by pulling over the trees too far to pick them more easily, thus breaking branches and stems. They should not be allowed to strip pick, that is, to run their hands down the branches and take everything that comes off. The thoroughness of the picking

of each individual tree must be checked, and fallen cherry should be collected after each round and pulped separately.

The loss of cherry by theft, in the field and in transit, must be prevented. Cherry weights should therefore be recorded in the field and checked again on arrival at the factory.

The initial inspection must take place in the field. Only ripe cherry should be accepted and paid for. Impurities such as stones, leaves and twigs must be removed. A second inspection should be made on the cherry when it arrives at the factory. In addition to a visual inspection, a count should be made on a small grab sample of 100 cherries, to indicate the picking standard. A count of 2-4% of under-ripe and overripe cherry is acceptable. Larger amounts cause unacceptable pulper problems, uneven fermentation, losses in weight and a poorer quality of green bean at the end of the process. As a result of this inspection, sorting may be required and any poor quality cherry should be pulped and processed separately. When handling large quantities of cherry, as on a plantation, hand sorting at the factory is not practical and so extra care must be taken in the field.

## 10.2 PROCESSING

In accordance with the Coffee Industry Corporation (Statutory Powers and Functions) Act, 1991, Part VI – Registration of Coffee Dealers, standard conditions have been issued by CIC to regulate the design, construction and operation of facilities for processing coffee so as to control the quality of the product.

The current regulations specify the basic requirement, for either wet or dry processing, is a **building** constructed of permanent materials and having the following features:

- (a) Office space installed with current communication facilities.
- (b) Secure and weatherproof.
- (c) Designed storage area for parchment and green bean, physically separated from areas housing furnaces, dryers and machinery.

### 10.2.1 Processing Methods

The main method of processing ripe coffee cherries into parchment is known as the 'Wet Process'.

**The wet process** is where the coffee cherry is pulped, and the released beans, largely free from the skin and pulp of the cherry, are then fermented, washed and dried to make parchment coffee. An alternative method is called 'de-mucilaging', using an eco-pulper. The wet process is the only process that is

acceptable in Papua New Guinea. The product, parchment, is sold to dry factories to process into green bean. The two major categories of producers, namely the large plantations and the smallholders, use different methods of wet processing their cherry, so a brief comment will be made about each one, before going on to describe the various types of operations in detail.

The current minimum equipment requirements for **Wet Factories** are:

- (a) Water supply and pump reticulation system adequate for designed plant capacity.
- (b) Weighing bay appropriately built to weigh cherry coffee with internationally accepted scales and/or standard scales.
- (c) Receiving pit, washing and conveying channels and fermenting vats adequate for designed plant capacity.
- (d) Pulper with sieve and re-passer adequate for designed plant capacity.
- (e) Kivu-type pumps for washing and transferring coffee.
- (f) Drying facilities adequate for designed plant capacity

### **10.2.2 Plantations**

In PNG, plantation factories vary considerably in size, handling from 5-200 tonnes of cherry/day at the peak of the season. However, with very few exceptions, all the pulping operations are done with a disc pulper, (to be described later). Most of the drying process, to produce the parchment coffee, is also done with machinery known as Asaro and Guardiola type driers, to speed up drying and to handle the large volumes of coffee involved. Nevertheless, most factories try to carry out at least some of the drying process in the sun, to improve the quality of their product. The usual method is on long lengths of 2 metres wide plastic groundsheet or 'sails'.

Most plantations also operate a dry factory, where they hull the parchment, clean and grade the green bean, and then pack it in special 60kg hessian bags, ready for export. The waste hulls from the dry factory are used to fuel the driers.

### **10.2.3 Smallholders**

The great majority of smallholders wet process their own coffee, using small drum pulpers, or other hand methods. Fermenting and washing is carried out mostly in bags. The wet parchment thus produced is then sundried on plastic sheets. The currently recommended procedures for processing cherry to dry parchment, which follow, apply to both plantation factories and small pulperies. To avoid repetition, these are given in general terms, to be put into practice where applicable and practical.

### 10.3 PULPING

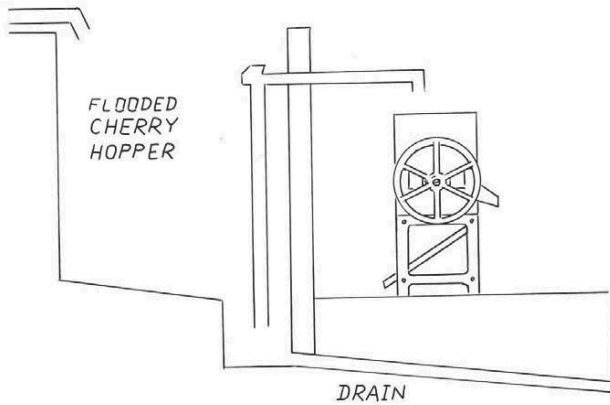
Cherry must be delivered to the factory, and pulped on the same day it is picked. It should be pulped within 8 hours of picking. If there is any delay, then the cherry must be stored under water to keep the temperature and the respiration rate as low as possible. The damage done by pulling the cherry off the tree, initiates the fermentation process within the cherry. When fermentation continues inside an unpulped cherry, it leads to discolouring of the parchment, and the further formation of fruity taints inside the green bean.

After inspection, the cherry is emptied into the cherry hopper. The hopper is designed to feed the cherry in a steady flow to the pulper. There are two types of hopper feed systems in general use, namely siphon feed and dry feed.

#### 10.3.1 Siphon feed

With a siphon feed (Fig 10.1), the hopper is filled with water prior to cherry delivery. The ripe cherry sinks to the bottom, from where it is fed by a siphon up to the pulper. The foot of the siphon tube should always be high enough above the floor of the hopper to leave any stones etc. behind. Provision must be made to release any blockages which may occur within the siphon feed pipe, which is usually 100mm in diameter for a four disc pulper. By using tee junctions, with an inspection plug, instead of elbows at every bend in the pipe, things like fragments of sacking can be removed when they cause blockages. With a flooded hopper, the light cherry floats, and can be raked over into a separate hopper and pulped separately. After pulping each day, the water should be drained out, the hopper cleaned of all cherry and the stone sump cleared.

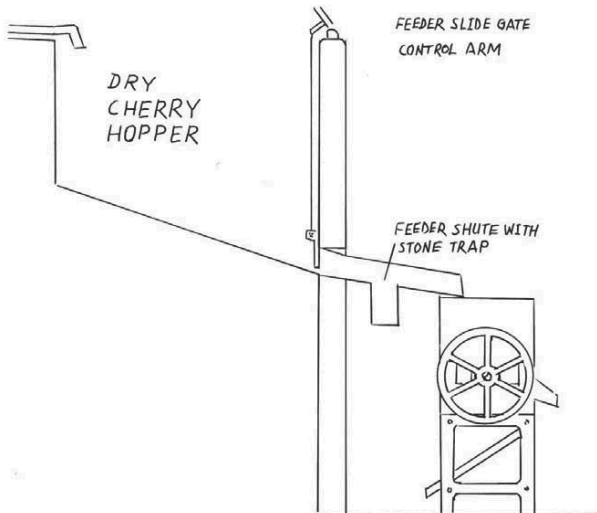
The main benefit of a siphon feed system, is the separation of light from heavy cherry, and the prevention of foreign matter such as stones or metal objects, being carried in to damage the pulper. It also conserves height, if there is a minimal amount of vertical fall to work on in the factory. The siphon feed hopper however, requires large amounts of water and the feed of cherry into the pulper may become more difficult to regulate or control.



**Figure 10.1: A siphon feed hopper**

**10.3.2 Dry feed**

This type of hopper is not filled with water (Fig. 10.2), but only has some water flowing into the bottom of it. The cherry is fed in dry, and the flow from the bottom of the hopper to the pulper is controlled by a simple choke or sliding placed over the outlet. The water is not used to actually transport the coffee, but more to provide a lubricant action. If the slope on the bottom of the hopper is not very steep, some extra water may be required, but it is nevertheless still called a dry feed hopper. A stone sump (trap) should be incorporated into the feed channel to the pulper.



**Figure 10.2: A dry feed hopper**

### **10.3.3      Disc pulper**

For large factories, the 4 disc pulper (Plate 10.1) is virtually the industry standard. These machines are robust, and many parts are interchangeable with the smaller 3 and 2 disc models. They are well supported by the PNG local agents, with both spare parts and technical advice.

#### **10.3.3.1      Disc pulper adjustment**

The speed of the pulper should be about 120 rpm. The knife bars must be set parallel to the disc, with a clearance of 0.7-0.9mm, depending on the local conditions. The thickness of a hacksaw blade is a very good approximation, and the use of an old blade as a feeler gauge makes it easy to both set and check this clearance. The knife bars should have sharp square edges, to stop the beans being wedged down into the gap and being nipped,

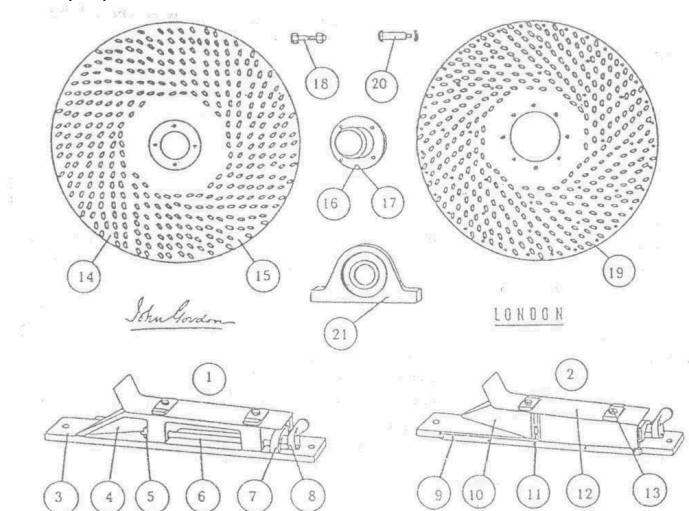


**Plate 10.1: Four disc pulpers with pregarder**

If the replaceable knife edge shows signs of wear, then it should be unscrewed and turned over, or turned end for end, to give a new square sharp edge. The ploughs, or pulping chops, which sit on top of the knife bars, guide the flow of cherries down the sides of the rotating discs. They too should be set parallel to the discs with a clearance of 6-8mm. The best guide to this setting is the width of a wooden six sided pencil, measured either across the flats, or turned a fraction to measure across the corners for the wider setting. This distance depends on the type and size of cherries that are being pulped, and so the factory manager should experiment to get the best results with the local product. If the setting is too close, larger beans will be nipped. If it is too wide, smaller cherries will not be pulped.

Experienced managers sometimes set the ploughs on a slight taper, to both speed up cherry flow and spread the wear on the knife bar. The bigger cherries will get caught at the beginning of the bar, and the smaller cherries further down the bar, where the plough is closer in. Further adjustments may be required during the year to counter the seasonal variations in the size of cherries and beans. With multi-disc pulpers, all disc clearances should be the same. When pulping, check that as much as possible:

- Beans are not being nipped;
- No beans are passing out with the skins;
- Only the smallest cherries, plus the unripe ones, remain unpulped and are passed on over the sieve or grader, to be pulped by the repass pulper.

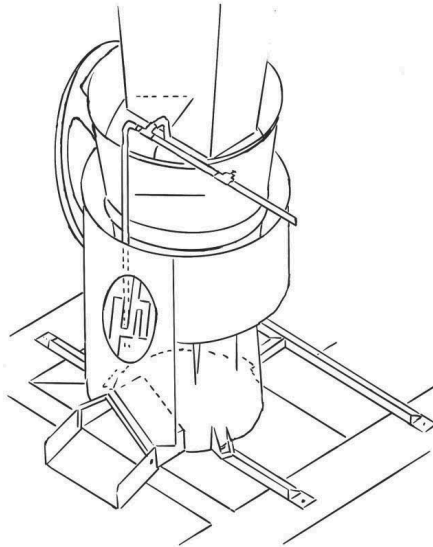


**Figure 10.3: Disc pulper parts**

- |                                                                |                                                   |
|----------------------------------------------------------------|---------------------------------------------------|
| 1. Left-hand pulping bar complete                              | 11. Detachable reed with screw                    |
| 2. Right-hand pulping bar complete                             | 12. Chop cover with fixed washers                 |
| 3. Steel base bar                                              | 13. Bolt and washer for chop cover                |
| 4. Left-hand pulping chop with reed                            | 14. Cast iron bulbed disc                         |
| 5. Back bearing for eccentric spindle with circlip             | 15. Copper-covered disc                           |
| 6. Eccentric spindle                                           | 16. Cast iron hub for disc                        |
| 7. Front index bearing for eccentric spindle with fixing bolts | 17. Brass hub for disc                            |
| 8. Adjusting lever with pin                                    | 18. Bolt with brass dome nut clamping disc to hub |
| 9. Knife edge with 5 screws                                    | 19. Copper disc, always sent in pairs             |
| 10. Right-hand pulping chop with reed                          | 20. Rivet and washer for copper disc              |
|                                                                | 21. Sealed ball bearing for shaft (complete)      |

#### 10.3.4 Penagos vertical drum pulper

An alternative is the Penagos pulper, from South America. This machine, while much cheaper, is also much more lightly built. Its design gives it a greatly increased throughput compared to the small conventional horizontal drum pulper. It will pulp up to 2.5 tonnes of cherry per hour, but it does not cope well with long hours of protracted work. It must be said however, that despite the fact that the major castings are in light alloy, the six vertical breasts, which is where the majority of wear occurs, are made of cast iron.



**Figure 10.4: The Penagos vertical drum pulper**

The flow of cherry in these machines is regulated by adjusting the large black plastic flaps at the bottom of the cherry hopper, as well as by the rate of water flowing through them. Any obstructions such as stones, or overloading the machine, will cause the safety shear pin to break. This pin is located in the hub of the fly wheel, and it is advisable to keep spare pieces of 7/64 inch fencing wire as replacements. It is dangerous to replace the safety shear pin with a pin of stronger material as this may cause more expensive damage.

Check for wear on the 6 pulping breasts, especially the depth of the canal at the lip. If the depth is less than 7.5mm, the breast should be replaced with a new one. Failure to do so will result in the loss of beans with the skins. Check that adjustments of all 6 breasts are the same. Once again use an old hacksaw

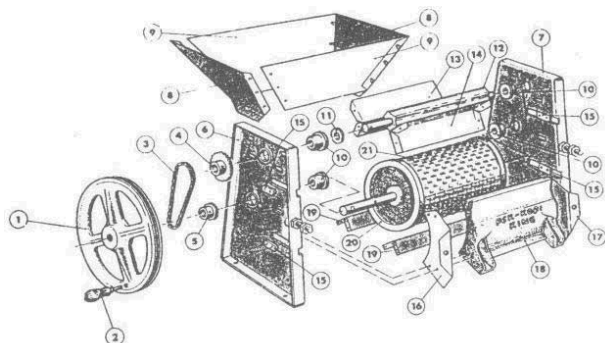


blade as a guide. Install the machine directly above the skin channel, so that the pulp will fall straight into it.

### 10.3.5 Hand operated drum pulpers

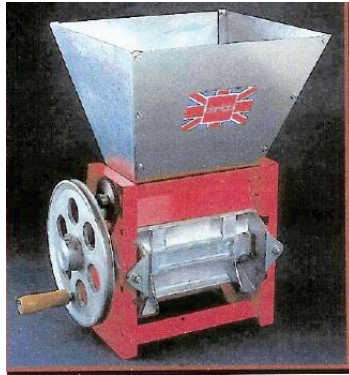
This is the type of machine commonly used by smallholders. Those models that have been tested have a throughput of 180-200kg of cherry per hour, with by far the biggest factor being the energy of the person, or persons, doing the turning. The same pulper, coupled to a small engine will pulp up to 600kg/hr. Even the smallest available engine, of 3hp, will easily drive two or three such pulpers, suitably linked together with shaft couplers instead of flywheels. This is a good way for an aspiring smallholder to gradually build up the throughput of his factory operation, by first adding the engine, and then an extra pulper to the lineup, as the need arises. Welded steel frames to do this are available at some farm supply stores and/or are easy to fabricate.

In the 1990s, CIC RGSD undertook evaluation of pulpers available on the PNG market. The recommended brand at that time was the single drum Denlab.



**Figure 10.5: The drum pulper**

- |     |                         |     |                             |
|-----|-------------------------|-----|-----------------------------|
| 1.  | Handwheel/pully         | 11. | Washer 20mm I/Diam          |
| 2.  | Handle bolt assembly    | 12. | Feed roll assembly          |
| 3.  | Chain assembly          | 13. | Rear cross member           |
| 4.  | 36 tooth drive sprocket | 14. | Front cross member          |
| 5.  | 15 tooth drive sprocket | 15. | Key                         |
| 6.  | Side member L.H.        | 16. | Adjustment bracket L.H.     |
| 7.  | Side member R.H.        | 17. | Adjustment bracket R.H.     |
| 8.  | Hopper end sheet        | 18. | Breast casting              |
| 9.  | Hopper side sheet       | 19. | Lower cross member          |
| 10. | Bearing                 | 20. | Roll assembly, hand powered |
|     |                         | 21. | Outer sleeve                |



**Plate 10.2 Hand operated drum pulper**

There are many configurations of linked drum pulpers available on the market, the most popular being a 'linked double drum' from Denlab.



**Plate 10.3 Double drum pulper with petrol engine drive**

#### 10.3.5.1 Drum pulper adjustment

Despite the large number of different brands on the market, the adjustment of all machines is the same. The critical measurement is the clearance between the bottom of the breast plate and the tops of the teeth on the drum. Once again, a piece of old hacksaw blade makes an ideal feeler gauge.

A hole, or a slot, about 15mm across, will be found low down on each side of the machine, where one can slide in a gauge and adjust the bottom of the plate. The top of the plate may be set out a millimetre or two further, to give a slight taper and speed the flow of cherry through the machine. However, the slightest bit too much and the machine will begin to nip a lot of beans.

A well set-up drum pulper should only nip two or three beans in every hundred, i.e. 2-3% of output. There are also two feeder plates at the bottom of the feed hopper, which can be adjusted to control the flow rate of the cherries past the feeder roller and prevent clogging. Using a lot of water to feed in the cherries, will both speed up pulping and reduce wear on the breast plate.

Attention should be paid to such wear, as it will cause a lot of nipping, no matter how correctly the breast plate is set, and it will permit the loss of good beans from the bottom of the pulper with the skins. The main weakness of the drum type of machine, is that the knife bar is an integral part of the cast breast plate, and cannot be easily renewed. Once the curved ridges on the inside of the breast plate lose their sharp edges, particularly on the bottom corners, the only way to repair them is either to grind them down thinner on top, using a small angle grinder, weld them up higher and then angle grind them down again, or else buy a complete new breastplate. The fact that some machines are made from a light aluminium alloy, instead of cast iron, makes them wear out all that much quicker, especially if dry cherries are fed into them. Water is a very good lubricant in this situation.

### **10.3.6 Eco-pulpers**

Previously called aquapulpers, these machines were designed to be used in tandem behind the disc or drum pulper. This machine removes the pulp and mechanically removes the mucilage, thereby avoiding the need for fermentation altogether. The wet parchment can then be dried straight away, all in the space of a few minutes from when the cherry enters the factory. This speeds up the rate of throughput in the factory and removes the requirement of tank space for fermentation. The mucilage removal stage of the process also gets rid of the remaining skins that have passed through the pulper, thus producing a cleaner parchment.

Ecopulpers are widely used in Central and South America, resulting in more uniform green bean quality than can be achieved by the variable standards of fermentation practiced by smallholders.



**Plate 10.4 Penagos ecopulper : combined drum pulper linked to demucilager**

### **10.3.7 Pregrading**

This name is given to the grading carried out immediately after pulping. It literally means pre-fermentation grading. The machine used may be in the form of sieves, such as the older type shaker sieve, or the commonly used rotary sieve. The function of the sieve is to separate the pulped beans from smaller unpulped and imperfectly pulped cherry. The wet mucilated parchment falls through the holes in the sieve, whilst the larger diameter unpulped cherry and skins pass over the top and are fed into the repass pulper.

However, a much improved machine is the Aagaard pregrader, named after the Kenyan coffee planter, who invented the machine in the 1950's. The Aagaard pregrader not only separates the unpulped cherry, just as an ordinary sieve would do, but it also floats off the lights and the seconds, because its slowly oscillating sieve is moving under water. The raw (still mucilated) parchment coffee, separates into heavier beans or firsts, which sink down to the bottom of the tank, and the less dense beans, which float, or else get worked up the face of the oscillating screen. The floaters and the skins and unpulped cherries are then separated by size to make two streams which go to either side of the repass pulper, which can have a different setting on each side. A much more even fermentation results in an improved quality, when these various streams are separated out and fermented separately.

### 10.3.7.1 Aagaard pregrader adjustments

The efficiency of the pregrader is dependent on a proper rate of water flow, and this is the only thing that needs to be adjusted for the clean separation of good coffee. The major point of wear on these machines is the chain driven elevator, which lifts the good coffee up out of the bottom of the machine. If the factory has an adequate water supply, then this elevator, which is only meant to conserve water, can be done away with and a simple siphon feed of three inch pipe can be used instead. If the top of the pipe is level with the top of the machine, then the rate of flow can be altered by just leaning the pipe over at the appropriate angle.

### **10.3.8 Repass pulper**

Normally a single disc model, this machine takes the overflow from the sieve. If taken from an Aagaard rather than a sieve, it is possible to set each side of the disc for a different size, to cope with the dual output of overflow or repass material from the Aagaard. This overflow contains the hard under-ripe cherries, and the smallest cherries that have come through the main pulper untouched. The plough should be set closer than that of the main pulper setting, in order to pulp small cherries. For maximum efficiency, the repass pulper settings should be frequently checked and adjustments made accordingly.

The output of the repass pulper is normally fermented separately to be processed and either sold as a low grade coffee, or else is carefully handpicked over before being mixed back into the main quality line.

## **10.4 FERMENTATION**

After pulping, the wet parchment must be held for some time, usually 34-36 hours (depending on temperature/altitude) to allow the mucilage layer or mesocarp to completely ferment and disintegrate, so that it can be washed off the beans. In big factories, the large volume of wet parchment needs to be held in special fermentation tanks, whereas smallholders can ferment their small amounts in bags, wooden boxes or other perforated containers.

The best results are given by allowing the fermenting beans to drain freely. Beans that are fermented under water, or in a water tight container, take much longer than if some oxygen from the air is available in the small airspaces between the drained coffee. Fermenting beans should also be kept warm, by bulking them up as much as possible to stop the heat generated by the fermentation from dissipating. Generally speaking, the quicker the fermentation process is achieved, the less chance there is of taints and off-

flavours developing. Sourness, which is caused by poor fermentation and poor washing, should be avoided at all costs.

One should avoid fermenting beans in any sort of un-painted steel container. Parchment may be washed in an old oil drum, but wet parchment or fermenting coffee should never be left next to steel for more than a few minutes. As well as discolouring the parchment, either with rust, or more often with a blue-black metallic sheen, a metallic taste can be given to the liquor.

#### **10.4.1 The fermentation test**

The best way to tell if fermentation is complete is by taking a handful of the fermenting coffee and grasping it strongly enough to squeeze some out through the fingers. When the beans feel gritty or rough, like stone pebbles, then fermentation is complete. If however they still feel slippery, then more time must be given. Under normal conditions, fermentation is completed in about 36 hours. If temperatures are low, or the coffee was picked after heavy rain, which washes the natural ferment off the cherries, extra time may be required. If the process takes any longer, then expert assistance should be asked for, because diagnosis of fermentation problems is a skilled business. Just leaving the coffee 'for as long as it takes' is not good enough, and, as mentioned previously, over-fermentation is the major factor leading to off-flavours.

#### **10.4.2 Use of enzymes**

For large factories, where time is important, the rate of fermentation can be speeded up if enzymes, such as Ultrazym or Pectozyme are used. For instance, the use of 20 g of Ultrazym 100, at the start of fermentation of 6,000 kg of cherry (i.e. 1,000 kg of finished green bean), can reduce the fermentation time from 36 hours to around 14 hours. It has also been reported that as well as reducing fermentation time, better weights of green bean are also produced. Enzymes are available from most commercial plantation suppliers, but they can be expensive.

#### **10.4.3 Making your own enzymes**

It is possible to make up an enzymatic mixture for oneself, which is equally as effective as commercial enzymes. If it is possible to separate the lights from freshly pulped coffee, either by flooding the fermentation tank whilst the pulpage is going into it, and skimming them off, or by use of an Aagaard pregrader, when the process is quite simple.

Simply place the freshly separated lights in a plastic bucket, or buckets, of water, and leave them for around five days. This process of course requires sufficient buckets or tubs to hold each day's supply separately for the week. On the fifth day, when all the coffee has been pulped, the lights floated off and the tanks drained, then the first container of fermented lights, from the previous week, is strained and the solids discarded. The liquid fraction remaining is then diluted down with water to be mixed into the tank of fermenting coffee.

This 'brew' is very effective in speeding up the natural fermentation of the coffee, and can ensure overnight fermentation. However, it must be made every time from freshly pulped cherries. This is because, as well as the majority of beneficial bacteria, the natural bacteria flora of the soil and wind, which covers the sticky surface of the ripe cherries, also carries lesser numbers of other species of bacteria which can cause problems. If one tries to maintain the brew by using some of a previous batch, these minor bacteria can build up to the point where they may cause off-taints or other problems.

#### **10.4.4 Uneven fermentation**

Fermentation will be uneven if excessive skin and unripe or overripe coffee is included in the batch. The overripe material is partially fermented already, and fermentation is very slow on under-ripe and unripe coffee. To provide the best conditions for even fermentation, coffee in fermenting tanks should be rinsed with clean water at least once a day, to wash off the already disintegrated mucilage, and also to dilute the build-up of organic acids in the tank. If a Kivu pump is available, coffee can be pumped out of a tank and back into it, or from one tank to another, to both mix it and even out the fermentation, and also to wash off the mucilage. Such a practice should be encouraged if the machinery and the water are available; the tank should then be left open to drain, so that a certain amount of airspace is left in the fermenting mass. Coffee ferments very slowly under water because the bacteria enzymes appear to require some oxygen in order to work well. Only the natural fruit ripening enzymes, present inside the cherry itself, appear to be able to work under water.

#### **10.4.5 Over fermentation**

Prolonged contact of the beans with the solubilised mucilage and other fermentation products, damages the quality of the coffee by discolouring the parchment. It may also introduce 'fruity flavour', if the wet beans are left in contact with skins and pulp. 'Fruity flavour' is the precursor of 'sourness', which is due to the production of 'longer chain' organic acids like propionic and/or butyric acid. The way in which this happens is that instead of bacteria

doing the work, the fermentation is taken over by wild yeasts, which first of all make alcohol and fruity flavours. Then the alcohols break down into both, acetic acid (vinegar) which is harmless, and other deleterious acids, which make sour coffee. Because yeasts prefer anaerobic conditions, lack of drainage and the presence of excessive pulp and skins can push the fermentation in their direction by restricting oxygen transfer in the fermenting mass. Fermenting coffee should therefore be washed, at least every day, and, as soon as the beans feel gritty, they should be given a final wash, and then left to soak overnight in clean water.

Washed parchment should be soaked to produce a superior quality coffee with a better liquor or cup taste (see Section 10.6).

#### **10.4.6 Fermenting coffee in bags**

Whilst it is strongly recommended that coffee should be fermented in as large a volume as possible, i.e. in tanks, many smallholders use white plastic chicken feed bags to ferment their parchment. It is possible to produce good coffee from bag fermentation, but some points must be watched. White polypropylene woven plastic sacks are virtually waterproof, and the liquified mucilage or 'gris blong kopi', cannot drain freely away from the fermenting coffee.

Bags used for fermenting coffee should be punched full of holes with a red hot nail or piece of wire. The bags of fermenting coffee should be heaped up together, to maintain as much heat as possible in the fermenting mass. If the pile can be covered with other bags or banana leaves, this will also retain heat. The bags should not, however, be buried in a pile of hot fermenting coffee pulp, because then the air cannot get in and the parchment will be discoloured by leachate or the dirty water from the coffee pulp. After each fermentation, the bags must also be washed as clean as possible. Dirt in the bags can lead to dangerous taints and off-flavours being introduced.

Wooden boxes may be used, but care needs to be taken to maintain the hygiene of the boxes.

### **10.5 WASHING**

During the fermentation process, coffee should be washed every morning, until fermentation is complete. At each wash, all the decomposed and liquified mucilage should be removed to leave only that which is still firmly adhering to the beans. Removing the solubilized mucilage allows the air to enter the fermenting mass and avoids all the problems of anaerobic fermentation.



Delay in washing can give problems similar to over-fermentation, with the resultant flavour defects mentioned above. A good supply of clean water is essential, as several rinses or changes of water may be required. Washing is currently carried out in many ways, using:

- bags;
- small containers;
- fermenting tanks – by hand;
- separate washing tanks – by hand or with pump;
- washing channels;
- mechanical washing machines.

#### **10.5.1 Washing coffee in Bags**

Washing coffee in bags is not only hard work, but parchment may not be thoroughly washed. It is nevertheless a practice much used by smallholders, because they have no other practical way. Bags are easy to handle, so that the fermenting parchment can be easily moved, kept in the house at night for security, and taken to a nearby stream for washing.

The best way to wash coffee in a bag is to push a hose pipe down into the bottom of the bag and, while stirring the coffee, float up as much of the skin and the lights as possible and flush them out of the bag. However, few smallholders have access to piped water, and there is an unfortunate reluctance to flush out the lights or empty parchment and fragments, to leave only clean sound heavy parchment in the bag. Nevertheless it is only sound heavy parchment that has any value and the lights simply become part of the coffee buyer's 'recovery ratio', which he has to calculate and delete before he offers his price to the seller.

#### **10.5.2 Washing in a tank**

Washing is done in small pulperies by adding water, stirring with wooden paddles and draining off the liquid. In larger factories, which have electricity, the use of a Kivu pump to circulate the fermenting coffee from one tank to another is a much better option. Kivu pumps are specially designed with a large smooth open impeller and they run at a slow speed. In this way they do not cut or bruise the coffee parchment as it passes through them. Any type of 'vortex' or 'non-macerating' trash pump which is capable of pumping solids is quite suitable. Most small petrol engine portable fire pumps are ideal, if they are run at a slow speed for circulating and washing coffee, and at a high speed for pumping water. Such versatility and portability makes them a very useful piece of equipment to have in a small factory.

Tanks used for washing coffee must have an efficient draining facility, as two or three washings may be required. The use of a fermenting tank may take the place of a separate washing tank, as long as it will hold water for long enough to do the job in hand. The best option here is to cement a piece of 75mm or 100mm plastic or steel pipe into the drain from the tank and use a 'test-plug' as a stopper or tap.

### **10.5.3 Washing channels**

A washing channel is a very useful adjunct to any wet factory because, in addition to washing, parchment is also graded according to weight. A washing channel is usually made of concrete, about 600mm wide, 40 metres long, normally folded on itself, and has a gentle slope of about 1 in 200 or 0.5% on the floor. The mode of operation is as follows. Once fermentation is completed, the wet parchment is pumped into the top end, with lots of water. As the mixture flows down the channel, the heavy parchment is pushed back against the current of water with the use of wooden paddles, allowing the skins and lights etc. to float off. With the aid of strategically placed wooden battles or boards, that slide into slots cast in the walls of the channel, the sound heavy parchment can be separated from the lighter coffee or 'seconds' to provide a top grade perfectly clean and very even sized parchment.

## **10.6 UNDER WATER SOAKING OR TWO STAGE FERMENTATION**

Immediately after final washing is complete, it is recommended that the 'firsts' coffee should then be left under clean water for another 16-24 hours. In case of emergency e.g. if drying space is limited, the coffee may be left to soak for longer, but certainly no more than 48 hours, providing that the tank is changed with fresh water after 24 hours. If separate tanks are not available, then fermenting tanks can be used, if they can be made water-tight. This so called second stage process was originally developed in Kenya, where it has been a standard practice for many years.

Initial test results in PNG also support this recommendation. Soaking ensures that any brown discolouration chemicals are also leached from the beans, thereby enhancing the colour and thus the quality of the coffee. However, the dissolving out of some of the sugars and other water soluble compounds, does result in a slight loss in weight. Overseas research indicates that some of the caffeine, and other bitter phenolic compounds, called chlorogenic acids, are also reduced by soaking. Unfortunately, soaking may also cause embrittlement and increased cracking of the parchment upon rapid drying. Nevertheless, because of the present trends in 'health consciousness', there are many overseas buyers who are specially looking for lower caffeine contents in their coffee.

## 10.7 DRYING

### 10.7.1 Drying parchment coffee

Parchment coffee is dried in two stages:

1. Skin drying  
This is when the free surface water is removed, to leave the parchment dry to the appearance but with the bean still moist and soft inside. Skin drying reduces the overall moisture content of the parchment from around 55%, down to about 42% moisture content dry basis (mcdB). Once the parchment skin is surface dry, the danger of spoilage is much reduced, but the coffee should not be left at this stage. If for any particular reason coffee has to be kept for even just a few days before drying is completed, it must be dried down to at least the soft black stage as a minimum requirement.
2. Main drying  
As coffee is further dried, it goes through several stages which can be determined by simple tests and by looking at the colour of the inside of the bean, as indicated in the following table:

**Table 10.1 Bean colour as an indicator of moisture content**

McdB (%)	
45-40%	Skin-dry. No water between bean and parchment.
40-35%	White stage. Parchment soft.
35-32%	Opaque stage.
32-25%	Very soft black stage. Bean partially opaque.
25-20%	Soft black. All parts of bean coloured black.
20-16%	Medium black. Bean easily marked by teeth.
16-14%	Hard black. Bean marked by teeth with difficulty.
14-12%	Colour change. Blackness disappears.
12-10%	Fully dry. Translucent jade green colour. Only barely marked by teeth.
10-8%	Over dry. Bean fractures when bitten.

The current standard for the maximum allowable moisture content is between 8% and 12.5%. However, it is believed that, because PNG coffee is grown under high rainfall conditions, the physical structure of the green bean is more spongy and hygroscopic (water absorbing) than coffee grown in drier climates. It is recommended therefore that parchment should be dried down to at least 10.5% or perhaps even lower, to give a good keeping quality of green bean that could be exported as a superior quality product. The choice of final moisture content should allow for the effect of conditioning, i.e. the evening

out of moisture between the centre and the surface of the bean. A balance must also be struck between the loss of revenue due to loss of weight, and the gain of revenue due to improvement of quality.

During final drying, the parchment skin should remain intact, with the shrunken bean remaining protected from the air, completely separated from the hull, but still inside its compartment. The best way to store coffee for any length of time is in this dried parchment form. Once coffee is hulled, and the surface of the green bean is polished or abraded, its protective coating is removed and deterioration of the bean by oxidative changes will begin. Polished green bean should never be stored for more than a month or two.

### **10.7.2 Cracking of parchment and case hardening**

Skin drying removes a lot of moisture from the wet parchment, and brings about a good deal of shrinking of the bean inside. This causes strains on the husk or hull of the parchment as the silver skin layer on the bean pulls away and separates from it. If the skin drying process happens too quickly, especially to those beans on the top or the bottom of the layer, wherever the heat is being applied, the parchment husk will shrink more than the bean inside will allow it, and it will begin to split and crack. This then creates a situation where, because those parchments which are split allow the green bean inside them to dry at an even greater rate than before, the whole batch dries very unevenly.

Cracking of parchment can be avoided by frequent stirring and moving of the coffee when it is drying, so as to keep the moisture loss as even as possible. Leaving coffee exposed to the full heat of the midday sun when it is being sundried is also a bad practice which is sure to cause cracking. Such extreme heat, whether by sun or machine drying, also causes what is known as case hardening. The outer layers of the too-rapidly shrinking bean are dried, brittle, hard and impervious, whilst the inside of the bean is still soft with moisture trapped inside. The stresses thus created result in micro-cracking of the surface of the green bean itself, and a subsequent definite loss of quality, particularly when the green bean has to be stored for long periods.

### **10.7.3 The benefits of sun drying of coffee**

Sun drying of coffee parchment improves its quality, by the bleaching effects of the ultra-violet light in the sun's rays. The brown discolorations are reduced, and any chlorophyll residues in the silverskin, from under-ripe cherries, are bleached or deactivated in some way. Furthermore, work done in Africa indicates that a minimum of 50 hours of exposure to sunlight emphasizes the blue-green colour of the coffee bean. That same bluish colour

indicates to the coffee liquorers that the coffee will have a certain desirable flavour and it is an intrinsic quality factor of coffee in trade, which is so often missing from machine dried coffee.

#### **10.7.4 Good sun drying practices**

In PNG, plastic sheeting, spread out on the ground, is the method most commonly used by those smallholders, farms and plantations involved in the sun drying of their coffee. This method is cost effective, but not recommended because of:

- The possible introduction of dust, stone and dirt into the parchment;
- The sweating of the coffee in the plastic sheets when they are folded over, in wet weather, or during the heat of the day;
- The labour intensive nature of the process, particularly the amount of hand labour required for raking and stirring, to dry the coffee evenly;
- The time consumed in the gathering and re-bagging of parchment.

The preferred method of sun drying coffee is on raised tables, built with floors of 4mm woven wire mesh. For ease of stirring, the parchment tables should have dimensions of 0.8m in height, 0.9m in width and 30 m long, i.e. the length of a roll of coffee tray wire. Coffee on drying tables is aerated naturally from underneath and can still continue to dry even when it is covered. It does not develop musty smells and taints, like wet coffee which has been wrapped up tightly for lengthy periods in impervious plastic sheets. The problem here is that when beans sweat, it is not pure water that comes out. Just like the human body, coffee beans sweat a salty/sugary solution that breeds micro-organisms very quickly, and the bacteria, and worse still yeasts, rapidly produce the off-odours and flavours. When coffee is dried with lots of air in circulation, the moisture actually evaporates inside the bean, leaving all the salts and sugars inside, where they should be for a heavier product, and only water vapour permeates out through the surface of the bean.

In direct sunlight, wet beans can get heated to nearly 40°C and nearly dry beans will go well up over the danger level of 50°C. This is especially so if coffee is dried on concrete surfaces or barbecues. Care should be exercised during the middle of the day to cover the coffee, or to shade it in some way.

#### **10.7.5 Combination drying**

The appropriate method for plantations who wish to improve the quality of their coffee by some sun drying, is to skin dry the wet parchment to the soft or medium black stage by machine, and then finish it off by sun drying on plastic ground sheets or on tables. By skin drying in an Asaro drier, the cracking of parchment is minimised or even avoided, so that the whole batch dries very

evenly, and the need for a long conditioning period before hulling is much reduced. During the main drying period in the sun, the coffee should be thinly spread, to avoid sweating. Such a finishing process could be completed within 4 to 5 days, when there is adequate sunshine available.

The most dangerous period of drying is at the skin drying stage when, as in sweating, bacteria, yeasts and moulds can grow on the damp surface of the parchment. It is preferable to get through this stage as quickly and as reliably as possible, and then the changes of the weather can be the more easily coped with at a later stage. Once coffee gets down to the medium black stage (20-16% mcdb), it can be bagged and kept for some time without loss of quality. This is the turning point, when a good manager can save his entire crop during bad weather or during peak harvest. At this stage, normal procedures can be completely overlooked for a week or so without harm.

#### **10.7.6 Machine drying of coffee**

When coffee is dried wholly in mechanical driers, it is essential to aerate and condition the beans at intervals, by stopping, or at least slowing, the drying process, to allow the moisture content to even out and avoid case hardening of the beans. Generally, coffee that is mechanically dried quickly, from 50% moisture content down to 12%, for some reason has a very low liquor score. Furthermore, to avoid damage in the cup quality and the bean colour, when mechanically drying coffee, the temperature should not exceed 50°C. While it is wet, the evaporative cooling effect is high, and it is very hard to even get near this temperature. But, as drying proceeds the temperature can rise, and care must be taken.

#### **10.7.7 Types of mechanical driers**

The most popular, and indeed the most versatile, kind of drier found in PNG is the Asaro drier. Other reasonably common brands are the rotary or Guardiola driers. They are very effective in finishing skin dry or soft black parchment down to the hulling stage.

The major advantage of the Asaro drier, is its large plenum chamber or open space underneath the perforated steel floor, and its effective drainage system. This allows wet coffee from the soaking and washing tanks to be pumped straight into it by means of a Kivu pump, and the water simply drains out the bottom, leaving the coffee. This is a great labour saving method of moving coffee around the factory. However, all of these driers are now becoming expensive to run, due to the rising cost of electricity.

Regular maintenance of the drying machinery, in particular the heat exchanger, is necessary for quality assurance.

### **10.7.8 Future directions**

With increasing costs for energy, and on the world markets that also equates to increasing costs for chemical fertilisers, the coffee industry can no longer afford to use energy intensive process like mechanical drying. Nor should it be discarding or burning its own organic wastes, and then importing all the fertiliser that it needs. The rapid escalation of popularity and demand for organic coffee also points toward the recycling of as much of our industry's organic wastes as possible. Some plantation managers report that they are getting less returns than before from their use of chemical fertilisers, because the soil structure and organic humus levels seem to be deteriorating.

If solar drying is coupled with a program of waste treatment, which can return all the hulls, pulp and skins, complete with their fertiliser content, back to the soil as humus and soil improvers (see Section 7.4.4.8 ), then we may yet be able to survive, and indeed prosper, in times of low commodity prices.

## **10.8 DRY FACTORY OPERATIONS**

### **10.8.1 Registration**

In accordance with the Coffee Industry Corporation (Statutory Powers and Functions) Act, 1991, Part VI – Registration of Coffee Dealers, standard conditions have been issued by CIC to regulate the design, construction and operation of facilities for processing coffee so as to control the quality of the product. The regulations may change from time to time. The currently applied Regulations issued in 2009 set out minimum requirements for registration of dry factories as:

Equipment requirements for **Dry Factories** will be standardized and for a minimum of one [1] tonne per hour capacity shall be:

- (a) Hot air dryer adequate for designed plant capacity.
- (b) A De-stoner is to be installed ahead of the Huller for designed plant capacity.
- (c) Huller-polisher adequate for designed plant capacity.
- (d) A Size-Grader capable of grading green bean into different grades or sizes for designed plant capacity.
- (e) A Catador adequate for designed plant capacity.
- (f) A Densimetric table at the output end of the line of machines adequate for designed plant capacity.
- [h] An approved Combined Huller may be substituted for the items specified in **(b), (d) and (e)** above.

### **10.8.2 Conditioning parchment for hulling**

By whatever means parchment is dried, there are sure to be small differences in the moisture content, both from bean to bean, and also from the centre to the outside of each individual bean. It is difficult to hull parchment when its moisture content varies in this way, so it is always best to store dried parchment in a bulk bin for at least a week or more, in order to even out the moisture content.

### **10.8.3 Hulling and polishing**

The traditional way of hulling parchment coffee is a high energy process where a powerful motor turns a large spirally fluted shaft or auger inside a slotted cage, and the coffee beans are forcefully screwed along the gap between them to have all their outer hulls and the silverskin rubbed off against each other. If the moisture content of the parchment is not between 10 and 12% mcdb, the machine is not carefully adjusted, or the parchment is dirty, the hulls will not break up cleanly and the machine will become jammed or impacted. It then has to be dismantled and cleaned, or else the coffee will become badly overheated and mutilated. Hulling is one of the more skilled operations in the processing of coffee. Once the hulls are removed, the green bean can then be polished, by being put through another similar but more gentle action of mechanical rubbing and abrading, to remove as much of the silverskin as possible and give the beans a shine.

On some equipment, these two actions are combined, in two sections of the one machine (Fig. 10.7). The hulling section is made of cast iron, and the polishing section of bronze. In small plants, the coffee can simply be put through the same machine twice, with less pressure applied on the second pass.



**Plate 10.5: A combination huller/polisher**



#### **10.8.4 Impact hullers**

Because of the large amount of heat generated in the traditional ‘screw press’ hulling process, and the damage that heat does to the eventual cup quality of the green bean, the use of ‘cross beater’ and ‘impact’ hullers is increasing. In these machines, the parchment is thrown at a plate or anvil, to break up the hulls. This takes very little horsepower, but removes the majority of the hulls. The coffee can then go through the traditional polishing process at a much lower temperature. Impact hullers are not expensive to maintain.

#### **10.8.5 Wear on hulling machinery**

It must be emphasized that the abrasive action of coffee hulls is such that, as well as polishing the surface of the green bean, it also wears down the inside surfaces of the huller. This is why the internal parts of a screw type huller are replaceable, and they should be checked every season. Processing smallholder coffee, with a high foreign matter content, can wear out an auger in 1,500 hours, or less. When the machine is worn and smooth, much more pressure has to be applied to polish the green bean, by adding extra weights on the outflow restrictor. Such excessive pressure will overheat, indeed cook, the green bean and a serious loss of cup quality results.

### **10.9 GRADING, CLEANING AND SORTING**

#### **10.9.1 Green bean grades**

The grading of green bean into different sizes is done immediately after hulling. The sale of the green bean to exporters is made on the basis of cup quality and further separated according to bean sizes.

In PNG, the machines used, (see Plate 10.6), have shaker sieves fitted with perforated screens of different sizes. Bean size is determined by its width, but not its length. The size of the holes in the screens are usually, for historical reasons, measured in 64<sup>th</sup> of an inch. So, for example, a no. 18 screen, i.e. 18/64's in diameter, will let everything pass through it, except those extra large beans. Screens from Europe can be measured in millimetres. Table 10.2 gives the current coffee grades and the size differentiations.

In general, the better the coffee trees are cared for and the healthier they are, the bigger are the beans, the higher their content of sugars and aromatic oil, and the better their quality. So, a simple grading by size is a fair indication to exporters and merchants of the overall quality of what they are buying.

In addition to the specifically sized grades A and B, there are several general categories. Most smallholder coffee, because of the poor processing methods used, is sold as Y grade, because its taste has little relation to the size of the beans.

### **10.9.2 Cleaning and densimetric sorting**

Even after size grading, a lot of impurities can remain such as small stones, fragments of dried skin and broken fragments. A Catador is therefore required, by CIC regulations, to separate out objects lighter than coffee beans, by an upward blast of air. An enhanced cleaning and sorting operation can be done by means of a densimetric table. These machines move the green bean across an oscillating screen, with a draft of air coming up from underneath. This spreads out the beans into a range of densities, as they move across the surface. The upper and lower grades can be removed, and the main output of good bean sorted into 2-3 grades, depending on their individual weights as well as their size.



**Plate 10.6** A grading machine

### **10.9.3 Hand sorting**

While there are electronic sorting machines available to pick out those beans which are discoloured or have other defects, these machines have not been widely used in PNG. They are, however, standard equipment in Central and South American coffee factories.

In many operations, sorting is carried out by hand. Some factories use a conveyor belt to move a thin layer of green bean past a line of seated workers who concentrate on picking out the defective beans.

### **10.10 BAGGING AND STORAGE**

Coffee stores for both parchment and green bean must be dry, well ventilated, clean and secure. A coffee store should never be used as a temporary store for chemicals or anything else, because of the danger of the coffee picking up bad taints. Hulled and graded green bean is bagged directly into 60kg 'Export' double layer jute bags, which should be stacked on pallets or wooden slats 15cm above the floor, and kept away from walls. For good storage, the most important feature is the moisture content of the green bean. In PNG it is recommended that this should be as close as possible to 10.5%, for reasons mentioned in Section 10.7. Careful records must be kept of all coffee in the store, and each consignment sold must be of uniform quality.

### **10.11 PURCHASING SMALLHOLDER COFFEE**

Smallholder coffee can be bought either as cherry, or as parchment at varying degrees of dryness. When buying or working with cherry weights, the main factor to consider is the out-turn ratio. When buying parchment, it is the recovery ratio.

#### **10.11.1 Out-turn ratios**

As a general rule, one tonne of cherry will produce around 160kg of green bean. This represents an out-turn ratio of 6.25:1. However, practical results can be anything from 5.8:1 up to 7:1. The major factor is the moisture content of the cherries just before picking. Coffee picked after a heavy rain will have an out-turn ratio of close to 7:1. Coffee picked after a dry spell will be less than 6:1.

A major problem in buying smallholder cherry is the long delay between the picking of the cherry and its sale and eventual processing. As already mentioned, such delays cause over-fermentation, the production of fruity flavour and often sourness. Factory owners should be vigilant to detect this

problem and encourage the prompt marketing and processing of smallholder cherry.

**Table 10.2: Grades & Screen sizes for green bean**

Grade	Cup Quality	Maximum Defect allowed (Equivalent per Kg)	Raw Bean Colour	Odour	Bean Size		
A	Full, reasonably balanced, uniform, clean, cup; well pronounced body and acidity; rich and distinct fragrance and aroma.	10	Bluish green	Fresh and clean, no off odours allowed	Displayed as a Suffix. Where a specific screen size is designated the coffee must be uniform in size above designated screen size. No suffix means the coffee is mixed size.		
B	Regular, uniform clean cup; medium to high acidity and pronounced body; rich fragrance and aroma.	30	Even, green to bluish green		Screen No.	Screen Diameter (mm)	ISO norm
Y	May lack some uniformity in the cup; good acidity and body; some Fruitness/ wininess; good fragrance and aroma.	70	Pale green to green	Clean/ fresh, some fruitiness	18	7.14	7.10
					17	6.75	6.70
					16	6.35	6.30
					15	5.95	6.00
					PB	4.37 to 5.55 (single bean/ round shape)	4.40 to 5.60
Y2	Irregular cup profile; fair acidity and body; no foul or foreign flavour.	150	Mixed light green to green	No foul or foreign odours.	Mixed		
Y3	No foul or foreign flavour.	30% defects excluding good nipped beans. No foreign matter. Must be fit for human consumption.	Mixed	No foul or foreign odours.	Mixed		

### 10.11.2 Recovery ratio

The 'recovery' or 'return' ratio is the difference between the weight of parchment and its yield of dry, sound and clean green bean. A roadside buyer has to determine both the moisture content, and the amount of light beans, empty parchments and other rubbish in the seller's bag before he can work out his price. Good, sound, well washed clean and dry parchment has a recovery ratio of around 80%, due to the weight of the hulls and silverskin. A

badly under-dried smallholder sample, full of skin fragments, empty shells and other rubbish can have a recovery ratio of only 60%.

### **10.11.3 Moisture content**

The convention in PNG, for the roadside buying of smallholder parchment, is to set the price in relation to the moisture content of the coffee in question. Fully dried parchment is called 'machine coffee', because it can be put straight into the huller. No. 1 coffee needs two or three hours of additional drying before it can be machined, and No. 2 coffee 5 or 6 hours.

Further details of the classes of 'Dry Arabica Parchment' are given in Papua New Guinea Standard 1626 -2016 for Green Coffee gazetted by NISIT.

## **10.12 SETTING UP A NEW COFFEE FACTORY**

Because of the large number of possibilities, and the site specific nature of most designs for small coffee factories, it is not proposed to give any actual plans for coffee factories in this Handbook. However, the staff at CIC RGSD are available to advise, on the basis of a sketch plan of the area and some projected figures, on the amount of cherry/parchment to be processed each year. Most machinery manufacturers will now provide a full design, to suit the size of the planned operation.

### **10.12.1 Choosing a good factory site**

Big or small, the first point to be considered in the setting-up of any wet factory or pulper unit, is the need for a reliable, ample and unpolluted **water supply**, with sufficient pressure or head to give a good rate of flow. A small supply may be bulked up by storage in a large tank, which can deliver a large flow for short periods when required.

Water is needed:

- To enable the pulper to work properly;
- For transport of coffee waste through the factory;
- For washing the coffee;
- For cleaning the factory.

The amount of water required will depend on the type of cherry feed, the machinery used, the washing procedures and whether it is possible to recycle. For a large factory, as much as 90,000 litres may be required per tonne of green bean produced, although with recirculation, as detailed below, this can be reduced to 30,000 litres or less.

Ideally, the factory should be sited on sloping ground, with an angle of about 17 degrees. This will make construction easier and assist the smooth

movement of the coffee by gravity down through the various processes. This minimizes the use of both machinery and labour. Given the choice between sitting the factory on a slope, or close to a stream, the best long term choice would be to choose the slope, as it is a lot easier to pump water than to move coffee from one machine to another. The factory should be easily accessible by good roads, to be able to receive cherry in all weathers, and for the removal of bagged dry parchment or green bean.

### **10.12.2 Water use and recirculation**

If plenty of water is available, it is preferable to use sufficient to dilute the effluent or waste water flow from the factory as much as possible and minimise the pollution problem. However, for many reasons, such as eventual shortage of supply, storage costs, pumping costs and waste treatment, the general aim should be to economize with water.

If the supply is limited, it is possible to reduce the use of water by recycling. Water that is used for the pulper may be recycled by straining out the pulp and pumping it back to use again, perhaps several times over, but only for that day's pulping.

The first flush of water used for washing the fermented parchment held overnight, must be discarded immediately, because it contains all the liquefied mucilage, the main load of effluent. The second rinsing water, and the water used in a washing channel, can be recirculated for as long as required, the more so if the coffee will be put to soak for another day in a further final wash of clean water. What must not be done is to save used water from one day to the next, because that water will go foul overnight.

A major economy can be achieved by holding the 2<sup>nd</sup> rinse or washing channel water, used for washing coffee in the morning, for reuse in pulping another batch of coffee in the afternoon. This is recommended practice for large factories with good management practices, because care must be taken to prevent a 'feedback' cycle in which an infection or off-fermentation may start-up and be passed on from one day to the next, building up as it goes to create serious problems.

All wet factories are required to have a 'Permit to Take Water', or a 'Water Use Permit' plus a 'Permit to Discharge Water'.

### **10.12.3 Factory organization**

A well trained and experienced factory manager is essential to attend to the daily running and maintenance of the factory. The manager will be responsible for:

- The efficient receipt and correct processing of cherry to parchment or green bean;
- The daily organization and supply of labourers;
- The discipline of factory staff;
- The correct storage of parchment and green bean;
- The maintenance of machinery and equipment;
- The keeping of records for machinery running hours and maintenance;
- The maintenance of a stores ledger and a supply of fuels, lubricants and essential spares for all machinery and equipment;
- The implementation of machinery safety and anti-pollution regulations;
- The maintenance of the factory water supply;
- The maintenance of access roads;
- The implementation of efficient security measures, watchmen, fencing and security lights.

#### **10.12.4 Labour requirements**

The requirements given below are for a 3 disc factory handling 3,000kg cherry/hour. The following is given as a guide, actual numbers will depend on many factors, such as:

- Factory design;
- Reception;
- Sorting;
- Weighing;
- Methods of handling wet coffee, by pumps or by hand;
- The seasonal variation in ripe cherry inputs.

Many of the operations that are detailed below occur at different times of the day, and so can often be performed by the same team. The size of the team required therefore mostly depends on the largest single unit operation, plus the volume of cherry coming in at the time. The usual practice is to have a minimum sized team of permanent staff, and then use casual labour to meet the short periods when seasonal peaks occur.

#### **Reception**

One factory manager/supervisor for cherry reception and recording.

Two assistants for weighing, lifting bags etc.

#### **Pulping**

One man in-charge of the pulper.

#### **Washing**

Two men for intermediate washing.

Two to four men for final washing, depending if washing channel is used.

## **Drying**

Two men, if drying is carried out mechanically.

Two men per 140 m<sup>2</sup> of drying area, if tables or sails are used for sun drying.

This operation is labour intensive due to the frequent turning required.

## **Cleaning**

The pulping team should also be responsible for cleaning the factory. The cherry hopper, dry feed chute, pulper, sieve or pregrader, channels and floors should be **thoroughly cleaned** at the end of each day's pulping. Each day, before pulping commences, all the equipment should be checked again to see that it is clean and that the fermentation tanks to be used that day are also clean. If cherry or pulp is left in machinery overnight, it will pass through with the next day's fresh cherry, causing taints which will adversely affect the quality of the coffee. Such lack of cleaning is often the source of isolated 'stinker' beans which can seriously downgrade a whole batch of production.

### **10.12.5 Safety**

All exposed belts, chains, and other moving parts should be enclosed to protect workers from accidents, and to comply with safety regulations. Only the authorized operator and possibly an assistant, should operate factory machinery. All staff should be provided with, and trained with, the necessary Workers' Health and Safety (WHS) Standards set down by the Department of Labour and Employment.

The operation and maintenance of the machinery should follow the manufacturers' instructions.

If the factory works at night, adequate lighting must be available, both for safety, and to avoid operator fatigue.

The factory compound should be fenced, mainly for security reasons, but also to prevent unauthorized persons having excess to the machinery.

## **10.13 PULP AND WASTE WATER DISPOSAL**

Finding a safe and efficient method for disposing of coffee pulp and factory waste water is essential. Pollution of rivers and minor waterways can occur throughout all the coffee growing areas, and from both sectors of production. Government and the CIC have legislation governing the treatment of pulp and waste water.

### **10.13.1 Separation of pulp and waste water**

The first and major requirement is for the coffee pulp to be separated from any water discharged from the factory. The elimination of pulp solids will



substantially reduce the pollution load of the waste water. Separation can be done using a perforated steel plate (static screen). The stream of pulp and water is pumped over the top to the screen, the water passes down through the screen and the pulp builds up on top, until its weight makes it slide off. The water passing through the screen can be piped back for recirculation, or piped directly into seepage pits.

A series of 3 settling or seepage pits is recommended. Suitable reeds and rushes are used to extract soluble nutrients as the water progresses from pit 1 to pit 3. If it is not possible to dig a pit because the water table is too high, then channel the waste water into a piece of swamp or reeds before it gets into a stream. A method that is presently acceptable is to pump the pulp waste stream out into an open area some distance away from natural drainage, heap up the pulp for future use, and allow the water to drain away, preferably through a swampy area growing reeds and rushes.

CIC regulations require processors to provide (on request) written evidence of compliance with all requirements of the Department of Environment and Conservation as to pollution control including dust, noise and disposal of affluent/waste, as required.

Registered wet factories must have their skin/pulp separation system approved by the Corporation.

Certified registered processors must strictly comply with the certifying agencies' policy requirements on environmental issues.

The CIC RGSD can give advice on waste treatment systems and provide plans for static screens and other equipment.

#### **10.13.2 Use of coffee pulp**

Coffee pulp is a good source of organic fertiliser and should not be wasted, particularly if no other chemical fertilisers are being used. If raw wet pulp is being put back out around the coffee trees, or in a vegetable garden, then it should be spread widely and thinly, certainly no more than 5cm in depth. The pulp has first to be stabilized, by turning black, before it is of any value to the soil. Once pulp has gone black, then it will not go smelly, breed flies or drain any nasty liquids. If pulp is heaped up, or spread too thickly, then the air cannot get into it to allow the right kinds of bacteria to work, and the pile goes red and slimy in the middle. This reddish sticky and slimy material is caused by a 'silage' or 'sauerkraut' reaction, which manufactures large amounts of organic acids which drain out of the pile. These acids kill the roots of plants if heaps of red pulp silage are broken open and spread around as fertiliser. They

can also kill fish and other wild life if unstabilized pulp is allowed into streams and rivers.

Raw pulp used as a mulch, or in planting holes for young coffee, has a heavy demand for available nitrogen, and can restrict growth quite markedly until it is stabilised.

### **10.13.3 Stabilizing coffee pulp for use as fertiliser**

The best way to stabilize large volumes of coffee skins and pulp waste, is to compost it. The process of making compost, is when any sort of organic material is given sufficient nitrogen to encourage bacteria to grow in it, and then the material is kept open and mixed, so that these aerobic bacteria can work on the organic matter to break it down and turn it into humus, which is a valuable soil fertiliser and improver. A proper composting process dries out the material and concentrates it down to about one sixth of the weight and volume of the original pulp. Actively working compost bacteria also generate a lot of heat, which kills off all the flies and pathogens or disease creating bacteria. It also stops the germination of the lights, those undergrade coffee seeds washed out of the coffee, which can germinate later on in the compost and cause problems.

Depending on how much time, money and work area is available, composting can be achieved in as short as a week, if machinery is used, or three weeks by hand methods. If pulp is just heaped up and left, it can take as long as two to three years to break down.

For smallholders with land available, the cheapest and easiest option is probably to set-up their pulper in an area where they plan to put next year's garden. Then, after the season's pulping is completed, the heaps of pulp can be spread around with a shovel. By the next season, the previous year's pulp will be well rotted down forming a valuable layer of mulch, which can be raked or dug into the soil.

For large plantations, who do have some land available, the windrowing techniques used by the American MSW (municipal solid waste) industry appears to be the best available option. This has, at present, only been tested in PNG up to the pilot scale of operation. This process takes about three weeks, and requires the windrows to be turned once a week. The lowest cost machine readily available is an attachment that fits onto a front end loader, or onto the hydraulics on the back of a tractor. This 'compost auger' would handle windrows of pulp two metres wide and one metre high, and should easily cater for the biggest coffee plantations in the country. Such a machine has not yet been tested in PNG.

#### **10.13.4     The growing of organic coffee**

The recent escalation of interest in organic coffee, from overseas buyers in Europe, Japan and the USA, has excited many local growers and processors. The higher prices that buyers are willing to pay for a product certified to be free of herbicides, pesticides and synthetic fertiliser chemicals, has to be weighed against the reduced outputs and increased costs of organic coffee production. Even if all the available coffee processing wastes were recycled, it would provide less than 20% of the presently assessed fertiliser requirements for intensive coffee growing. However, if a non-intensive regime was planned, by the replanting of shade trees, particularly those with a high production of leaf litter, the slashing and mulching of weed growth and the recycling of factory wastes, by the methods indicated above, then a reduced but fully sustainable yield of a high value product may be envisaged.

#### **10.14 USEFUL PROCESSING FACTS AND FIGURES**

The following information has been gleaned by a succession of RGSD staff from many places. These numbers are to be taken as a guide only. Figures relating to ripe cherry vary significantly from place to place. In most cases numbers have been rounded off:

- 1,000 kg of cherry yields 200kg of clean dry parchment.
- 200 kg of parchment yields 160kg of green bean.
- The average 'out-turn' ratio is 6.25:1.
- The average 'recovery' ratio is around 75-80%.
- 1,000 kg of ripe cherry needs 1.5m<sup>3</sup> of cherry hopper space.
- 1,000 kg of cherry needs 0.6m<sup>3</sup> of fermenting tank space.
- 1,000 kg of cherry produces 0.5m<sup>3</sup> of clean wet parchment.
- 1,000 kg of cherry requires 20m<sup>2</sup> of sun drying area.
- 500 cherries weigh 1kg.
- 4,400 dry parchments weigh 1kg.
- 5,000 green beans weigh 1kg.
- The capacity of a disc pulper is 1,000 kg/disc/hr.
- The capacity of an Aagaard pregrader is 3 pulper discs.
- One bag of parchment coffee weighs 50kg.
- One bag of green bean weighs 60kg.
- 16.5 bags of green bean weigh one tonne.
- Bags of coffee close stack at 13 bags/m<sup>3</sup>.
- 1kg green bean gives 0.84kg of roasted bean.



## **11.0 CERTIFICATION OF COFFEE**

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### **11.1 INTRODUCTION**

Coffee Certification is the process by which coffee is guaranteed to have been produced in compliance with a number of agreed specific standards. It is the result of worldwide consumer demand for products that have been produced in a sustainable, responsible and transparent way.

Coffee Certification ensures many social, environmental and economic benefits, it also generally rewards producers with price premiums and improved access to international markets. This in turn improves the quality and long term sustainability of the industry.

### **11.2 WHAT IS COFFEE CERTIFICATION?**

Coffee Certification is a voluntary initiative involving all the stakeholders along a production chain, from the growers to the processors to the exporters. All stakeholders agree to promote and practice a number of specified social, environmental and economic standards in a sustainable and transparent way. Their compliance is evaluated and monitored regularly by an independent certifying body. If the standards are fully met, the coffee is duly certified. Some coffee is double- or triple-certified by meeting the standards of more than one certifying body.

Once certified, the coffee can be marketed as certified coffee, and as such it will attract a price premium. Regular on-farm inspections, examination of records and interviews are undertaken during annual audits by the certifying bodies to ensure that standards continue to be met. Annual inspection/certification fees are charged by the certifying bodies.

Certification bodies will often provide advice to growers on how to become more professional and competitive, and/or provide access to markets and support networks.

### **11.3 WHAT ARE THE COSTS AND BENEFITS OF COFFEE CERTIFICATION?**

Successfully negotiating the rather complex process of Certification (see Section 11.6), maintaining the agreed social, environmental and economic standards, and dealing with the annual audits of the certifying organisation, are major challenges, especially in the PNG context. They require a significant investment in time, much determination, and some costs.

Implementing the many necessary changes to the coffee production process, whilst complying with the required social standards (such as providing training

for workers), will represent additional costs for all coffee producers, at least initially. These additional costs, however, should be off-set by improvements in production efficiency. As the anticipated improvements in coffee quality become apparent, and the price premiums due to Certification are realised, there should be a net benefit to most coffee producers.

Producing coffee in a sustainable, responsible and transparent way, whilst complying with social, environmental and economic standards, should result in benefits for the environment, and all individuals involved in the production chain. It also benefits the consumers, who are reassured that they are consuming an 'ethical' product.

Specifically for the coffee industry in PNG, coffee certification may result in some or all of the following:

- Improved coffee quality;
- Improved production efficiency;
- Sustainable production;
- Increased access to markets;
- Higher coffee prices
- Less environmental damage due to coffee production;
- Better conditions for those working in the industry.

#### **11.4 COMMON STANDARDS REQUIRED FOR CERTIFICATION**

Coffee certification involves all those who participate in the coffee production chain, from grower to exporter. Standards are therefore specified for growing, storing, processing, packaging and shipping of coffee. All certification bodies incorporate three basic dimensions of sustainability, responsibility and transparency, namely the:

- Social dimension (acceptable working conditions for farmers and their families);
- Environmental dimension (conservation of forests and natural resources);
- Economic dimension (reasonable incomes, free market access, sustainable livelihoods).

Although the precise requirements of different certification bodies vary somewhat, this section summarises the most common elements of these three dimensions. These are described in terms of the baseline or core requirements, and the standards necessary for full certification.

### 11.4.1 Social standards

**Table 11.1: General social standards for coffee certification**

<b>Requirement</b>	<b>Baseline or core</b>	<b>Full certification</b>
Freedom of association	Begin processes to enable farmers to join independent organisations such as farmer associations to protect their interests.	Farmers have the right to belong to, found, or be represented by an independent organisation of their choice.
Discrimination	Incidents of discrimination, harassment or abusive behaviour are being addressed.	Equal rights with respect to gender, maternity, religion, ethnicity, physical conditions and political views.
Right to childhood education	Some children are not attending school. Child labour only acceptable as part of light family work outside of school hours.	All children of legal age are attending school.
Working conditions	A safe working environment for all family members. Provision of a health and safety programme. Assessment of risks and identification of hazards, communicated to all workers. Farm infrastructure and machinery is in good condition and poses no danger to health. Provision of safety equipment; provision of first aid kit; first aid training for one family member.	Fully implemented health and safety programme, including systematic monitoring.
Capacity and skill development	Farmers receive training to improve agricultural and management practices. Training available to all family members working in coffee.	A complete training policy is implemented which includes agricultural and management practices, including documentation of any training undertaken.

### 11.4.2 Environmental standards

**Table 11.2: General environmental standards for coffee certification**

<b>Requirement</b>	<b>Baseline or core</b>	<b>Full certification</b>
Conservation of biodiversity	Endangered or protected species not exploited. Endangered fauna not hunted and protected plants not removed. Natural vegetation is conserved and sensitive areas are protected (e.g. slopes, creeks, wetlands). A conservation programme is being developed.	Implementation of a conservation programme and this programme meets national law.

Coffee shade trees	Only native tree species to be used as coffee shade trees (only some certification bodies)	Only native tree species to be used as coffee shade trees (only some certification bodies)
Chemical use and handling	Pest, disease and weed levels are monitored and pesticide use is minimal. Less hazardous pesticides are used. Identification of health risks. Plan for safe storage, use and disposal of chemicals. Farmers trained in safe storage, handling, application and disposal. Protective clothing is available. Records kept of training. Some bodies require avoidance of most synthetic chemical inputs and genetically modified organisms.	A documented Integrated Pest Management system based on systematic monitoring and use of only lowest ranking pesticides. Records kept of chemicals used and rates of application on all crops, not just coffee.
Pruning	Implementation of a coffee pruning programme to promote the generation of new tissue.	Implementation of a coffee pruning programme to promote the generation of new tissue.
Soil conservation	Soils protected from erosion by use of vegetation and/or plant residues and other techniques. Vegetative ground cover and mechanical weeding are used to reduce agrochemical use whenever possible.	No signs of erosion.
Soil fertility and nutrient management	A fertiliser plan is defined according to soil and plant needs. Organic matter is recycled.	Fertilisers only applied in accordance with crop needs, based on soil and/or plant analysis. All organic waste is recycled and is used as fertiliser. Soil organic matter is maintained.
Water	All water resources are identified and measures taken to conserve water where possible. Processes in place to treat waste water from wet processing and sewage. Hazardous wastes are disposed of safely.	Maximum conservation of water resources. Identification of different waste waters and appropriate safe disposal of each.
Waste	Safe disposal of hazardous waste.	Minimal waste generation, maximum recycling, and waste is disposed of safely.
Energy	Potential use of renewable energy sources identified. Energy use reduced.	Renewable energy sources are used when available. Improved energy use efficiency.



### 11.4.3 Economic standards

**Table 11.3: General economic standards for coffee certification**

Requirement	Baseline or core	Full certification
Market information	Growers receive regular updates on farm gate prices connected to local markets and differentiated for quality.	Growers receive regular updates on farm gate prices connected to local markets and differentiated for quality.
Market access	The managing entity provides growers with services such as market information, financial credit, and supply of inputs in order to improve their access to markets.	The producer assesses the types of services required and the managing entity provides access to services at market rates for fertilisers, pesticides, equipment, credit, planting material and technical assistance.
Quality	Definition of quality parameters. Plan is put in place to monitor quality from the farm to the managing entity.	Systematic assessment of quality from farm to managing entity. Assessments in place for quality of cherry, parchment and green bean based on moisture content and defects present.
Record keeping	Steps taken to keep records according to producer's level of education. These include technical and financial records such as yields, inputs, costs and prices received. Templates for record keeping provided by managing entity.	Records kept on all technical and financial aspects of production. Records show improvement in farm's efficiency.
Commerce	Producers aware of pricing mechanisms attributed to coffee quality and can take advantage of these.	Documentation that reflects the functionality of pricing mechanisms.
Traceability	Coffee compliant with criteria of certifying body is kept separate from other sources.	Compliant coffee is kept separate and documentation on compliance is available.

### 11.5 COFFEE CERTIFYING BODIES OPERATING IN PNG

All major certifying bodies incorporate the fundamental principles described in the previous section, although each differs in their approach. Outcomes are shared in pursuing a sustainable livelihood for their members and guaranteeing their buyers products produced according to agreed standards. The main certifying bodies operating in PNG are as follows.

### **11.5.1 UTZ**

UTZ is a not-for-profit foundation for responsible farming and product sourcing. The founding mission of UTZ was traceability, utilising their comprehensive tracing system 'Good Inside Portal' (GIP). Producers can begin in the first year fulfilling the core criteria but must demonstrate that they are continually improving their production practices.

### **11.5.2 Fairtrade**

Fairtrade is a non-profit movement for helping smallholders in developing countries achieve better trading conditions and to promote sustainability. Its members do not depend on hired workers all the time, and run their farms mainly using family labour. It aims to provide producers with a price that covers the cost of production as well as offering additional premiums for producers to invest in their communities.

The Fairtrade Minimum Price acts as a safety net when prices are fluctuating. If the market price is higher than the Fairtrade Minimum Price, producers receive the market price.

### **11.5.3 Rainforest Alliance**

The Rainforest Alliance is an international non-profit organisation that works to conserve biodiversity and ensure sustainable livelihoods. Certification is managed jointly by Rainforest Alliance and the Sustainable Agriculture Network and their auditing division RA-Cert. Emphasis is placed on Integrated Pest Management models.

### **11.5.4 4C (Common Code for the Coffee Community)**

4C is a multi-stakeholder community organisation committed to promoting sustainability. Its mission is to achieve 100% coffee sector compliance with at least baseline sustainability standards.

The 4C structure permits baseline entry, provided certain criteria are met and producers can demonstrate that they are continually improving their practices. Compliance is illustrated by a traffic light system for each criterion. Ten Unacceptable Practices must be eliminated before it is possible to join the Association.

Small producers pay only a minimal fee, but they still have decision-making capacity within the organisation. Trade and industry members pay a much larger proportion of the funding.

### **11.5.5 Organic**

The umbrella organisation for organic certification is the International Federation for Organic Agriculture Movement (IFOAM). In PNG its regularity body is the National Association for Sustainable Agriculture, Australia (NASAA).

It addresses a growing worldwide demand for organic food. This does not just mean 'no chemicals' but also emphasises the use of ecological management principles. Some traditional forms of agriculture are chemical free but are not 'organic' because they do not follow these principles.

### **11.5.6 CAFE Practices**

Coffee and Farmer Equity (CAFE) Practices is Starbucks Coffee's comprehensive coffee-buying programme. It aims to ensure the supply of quality coffee while promoting social, environmental and economic standards. Its coffee rating system is based on 249 indicators, and farmers with high overall scores receive higher prices for their coffee. Thus high quality, sustainably grown, coffee is rewarded accordingly.

### **11.5.7 Nespresso AAA Sustainable Quality Programme**

Nespresso is the brand name of Nestle Nespresso, an operating unit of the Nestle Group. The Nespresso AAA Sustainable Quality Programme pays premiums for high quality coffee and the most sustainable farming practices. It works in collaboration with Rainforest Alliance.

## **11.6 THE PROCESS OF COFFEE CERTIFICATION**

The process of Coffee Certification is a long one, and before embarking on it, producers should be aware of all of its requirements. The process can be summarised as follows.

### **11.6.1 Selecting a certification programme**

Producers need to be familiar with the requirements of each certifying body and then make a decision on which programme to apply to. This decision is based on:

- Their current status of strengths and weaknesses with regard to the certification standards;
- Their production methods, and how they could be improved;
- The cost of certification;
- The potential markets.

### 11.6.2 Gap analysis

All certifying programmes require producers to undertake a gap analysis, or a review of current practices, to determine the disparity between the current situation and the standards required by the programme. This will provide the producer with an understanding of the gap, which practices are currently non-compliant, and what is necessary to meet the specified standards. This exercise is a self-assessment using a checklist provided by the certifying body.

### 11.6.3 Application and registration

Most organisations require producers to apply for registration or membership. This may be as simple as completing an online registration form, or contacting the organisation for a certification package. The applicant will be sent all relevant information, including a Code of Conduct, a guide to the implementation process, fees and requirements for supporting documentation.

### 11.6.4 Evaluation

The programme evaluates the application and provides feedback and recommendations on how to proceed to the next step of auditing.

### 11.6.5 Preparation for the initial audit

- The producer will be informed of the **auditor**, who is usually independent.
- All programmes incorporate a comprehensive **Internal Control System (ICS)**. This consists of rules, policies and procedures to provide reasonable assurance regarding the achievement of objectives relating to operations, reporting and compliance. They are a framework for administration and improvement, and are also a tool to monitor and assess compliance. The ICS will be explained to the producer.
- The producer will have to prepare **Documentation** on such things as technical and financial records on yields, inputs, costs and prices.
- The producer will be required to conduct a **self-assessment** using the standards checklist prior to the auditing.
- The independent auditor will issue an **invoice** for the auditing fees, and on payment of the fees, a **schedule** will be agreed for the audit.

### **11.6.6 Auditing**

The auditing process begins with an opening meeting with the producer. The auditor will then review production systems and documents, inspect production areas, and write a report collating all evidence of compliance. The audit will finish with a closing meeting with the producer.

The producer may be granted permission to trade if no major non-conformities are identified. This may be a temporary allowance to trade under certain conditions, but does not necessarily represent full certification.

### **11.6.7 Certification**

Certification will only be granted to applicants once all non-conformities have been resolved. Maintaining certification requires continual adherence to the relevant standards, which is monitored by the organisation's auditing process.



## GLOSSARY

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- anion** – An ion with a negative charge e.g.  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$
- apical dominance** – The influence exerted by the terminal bud in suppressing the growth of lateral buds.
- auger** (boring) – An instrument for boring in soil.
- biuret** (damage) – A compound formed during the manufacture of urea. It is toxic to some plants and can be especially damaging when applied to plant foliage.
- breather** (lungbranch) – See lung branch.
- butterfly stage** – The stage in the development of a seedling when the two cotyledons have expanded prior to the production of the first true leaves.
- cambium** – Cellular tissue from which growth of xylem and phloem occurs.
- capping** – The removal of the terminal portion of an orthotropic shoot.
- cation** – An ion with a positive charge e.g.  $\text{Mg}^{2+}$ ,  $\text{Na}^+$
- CEC** – Cation exchange capacity. The sum total of the exchangeable cations that a soil can adsorb. The ability of the soil to retain cations against downward leaching.
- chlorosis** – Yellowing of plant tissue.
- constrict** – To make narrow, cause to contract.
- contact pesticide** – Pesticide whose action is dependent on contact with the pest.
- crinkle leaf** – A syndrome where leaves become bent and distorted due to environmental factors or nutrient imbalance.
- cull** – To select and destroy a surplus (usually inferior) in a population.
- culvert** – A channel carrying water across or under a road.
- defoliate** – To remove the leaves from a tree.
- diurnal** - Daily
- ECEC** – Effective cation exchange capacity. The sum of the exchangeable cations ( $\text{Ca}^{2+}$  +  $\text{Mg}^{2+}$  +  $\text{Na}^+$  +  $\text{K}^+$ ) plus exchangeable acidity ( $\text{H}^+$  +  $\text{Al}^{3+}$ ).
- exudates** – Materials (chemicals) that ooze from plant cells.
- foliar feed** – Liquid fertiliser applied to the leaves by a sprayer.
- friable** – Easy crumbled.
- gley soil** – A soil developed under conditions of poor drainage, resulting in reduction of iron and other elements and in grey colours and mottles.
- halo** – A circle around a body.
- hull** – To remove the outer skin (parchment) of a fruit.
- hypocotyl** – Part of a seedling between the cotyledon and radicle; its elongation brings the cotyledons above the soil.
- infills** – Seedlings used to replace those that have died.
- inoculum** – A pathogen which can cause a disease e.g. fungal spores.
- ironpan** – An indurated soil horizon in which iron oxide is the principal cementing agent.
- kink** – A short backward twist in a root that may cause a break.
- lapse rate** – The rate of decline in temperature with increasing altitude.

**lung** (branch) – A main stem possessing only one primary branch, the remaining bearing heads having been removed during stumping.

**matrix** – The colour of the major part of the soil, excluding mottles.

**me %** - Milliequivalent percent. A measure of the concentration of the cations in the soil.

**Mottle** (soil) – A spot of contrasting colour. The mottled condition indicates a zone of alternate good and poor aeration, a condition not conducive to proper plant growth.

**MOU** – Memorandum of Understanding.

**mycelium** – The mass of hyphae (threads) which make up a fungus.

**necrotic** – A piece of dead tissue.

**orthotropic** – Tending to grow upwards (stems) or downwards (roots).

**parchment** – Dried coffee, retaining the outer seed coat.

**pathogen** – An agent causing a disease.

**pathogenetic** – To reproduce from gametes without fertilization.

**peat** – unconsolidated soil material consisting largely of un-decomposed organic matter accumulated under conditions of excessive moisture.

**pedestal** (soil) – A column of soil produced by erosion of the surrounding material.

**petiole** – The leaf stalk.

**phloem** – Softer portion of the plant vascular tissue that transport photosynthetic products to the fruits. Compare with xylem.

**phytotoxic** – Poisonous (toxic) to plants.

**plagiotropic** – Tending to grow horizontally or obliquely, like branches or lateral roots.

**P-retention** – The transfer of phosphate ions from the soil solution into insoluble and solid forms.

**proprietary** – An article or chemical, the manufacture and sale of which is restricted by patent.

**pustule** – An eruptive spot containing fungal spores.

**rejuvenate** (coffee)– To remove old bearing heads and bring up new suckers.

**rhizomorphs** – Fungal threads which have aggregated to form a branched network of cordlike strands.

**rill** – A small, intermittent water course with steep sides, usually only a few centimetres deep.

**shothole** – The formation of a localised lesion on a leaf, frequently followed by the falling out of the dead tissue.

**soil fertility** – The status of a soil with respect to the amount and availability to plants, of elements necessary for plant growth.

**soldier stage** – The stage in the development of a seedling when the two cotyledons, still contained in their seed coat, have been pushed above ground.

**surrogate** – A substitute for.

**synergistic** – A combined effect of chemicals that exceeds the sum of their individual effects.

**systemic pesticide** – Pesticide which enters the plant via roots or shoots and passes through the tissues, to control or come into contact with the pest.



**tilth** – The depth of soil affected by cultivation.

**turgid** – Swollen, inflated, enlarged.

**uredospores** – A type of spores (reproductive structure) produced by rust fungi.

**xylem** – Harder portion of the plant vascular system that transports water and dissolved minerals from roots to leaves. Compare with phloem.

## CONVERSION FACTORS

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<u>To convert</u> Imperial units	<u>Into</u> Metric units	<u>Multiply by</u>
<b><u>LENGTH</u></b>		
Inches	Centimetres	2.54
Feet	Metres	0.3048
Yards	Metres	0.9144
Miles	Kilometres	1.609
<b><u>VOLUME</u></b> (Cubic Measure)		
Cubic inches	Cubic centimetres	16.39
Cubic feet	Cubic metres	0.02832
Cubic yards	Cubic metres	0.7646
<b><u>VOLUME</u></b> (Liquid Measure)		
Fluid ounces	Millilitres	28.35
Pints	Litres	0.5683
Imperial gallons	Litres	4.5460
U.S. gallons	Litres	3.7854
<b><u>MASS</u></b>		
Ounces	Grams	28.35
Pounds	Kilograms	0.4536
Hundred weights	Kilograms	50.8020
Tons	Tonnes	1.0160

### AREA

Square inches	Square centimetres	6.4516
Square feet	Square metres	0.0920
Acres	Hectares	0.4047

### PRESSURE

Pounds/square inch	Kilograms/square centimetre	0.0703
Pounds/square inch	Bars	0.0689
Pounds/square inch	Atmosphere	0.068
Pounds/square inch	Kilopascals	6.89

### VELOCITY

Feet/second	Metres/second	0.305
Feet/minute	Metres/second	0.00508
Miles/hour	Kilometres/hour	1.609

### QUANTITIES/AREA

Pounds/acre	Kilograms/hectare	1.12
Ounces/square yard	Hundredweights/acre	2.7
Imperial gallons/acre	Litres/hectare	11.233
Fluid ounces/imperial gallon	Millilitres/litre	6.250
Fluid ounces/acre	Millilitres/hectare	70.05
Ounces/acre	Grams/hectare	70.05
Hundredweights/acre	Kilograms/hectare	125.54
Pounds/imperial gallon	Kilograms/litre	0.998

### DILUTIONS

Pints/100 imperial gallons	Millilitres/100 litres	125.0
Ounces/imperial gallon	Grams/litre	6.24

### PLANT NUTRIENTS

<u>Oxide</u>	<u>Elemental</u>	
P <sub>2</sub> O <sub>5</sub>	P	0.437
K <sub>2</sub> O	K	0.830
CaO	Ca	0.715
MgO	Mg	0.602

To use the tables in reverse just divide.  
i.e. to convert centimetres into inches, divide by 2.54.

## **SLOPE**

<u>Slope ratio</u>	<u>Percent</u>	<u>Degrees</u>
1:1	100	45
1:2	50	27
1:3	33	18
1:4	25	14
1:5	20	11
1:6	17	10
1:7	14.5	8
1:8	12.5	7
1:10	11	6
1:10	10	5.5



## APPENDIX 1

### SOIL SAMPLES

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#### A1.1 HOW TO COLLECT SOIL SAMPLES

It has been estimated that 33% of the fine roots, which are mainly responsible for the absorption of nutrients, occur in the top 10cm of soil, and 73% in the top 30cm. Thus it is the nutrient content of the topsoil that is of most interest to the coffee grower.

The simplest procedure for deciding on the actual soil depths to be sampled is to always use standard depths e.g. 0-15cm and 15-30cm. This is satisfactory if the standard depths fall entirely within a soil horizon, however, if an abrupt soil boundary occurs at say 10cm, a sample collected from 0-15cm would consist of a mixture of two different horizons, possibly of quite different origin and chemical fertility. The subsequent analytical results will be averages of the figures from each of the two horizons sampled (weighted according to the proportion of soils collected from each horizon). Such figures may be quite different from either horizon and would be of limited value. In this case, it would be better to collect samples from 0-10cm and 10-20cm.

It is recommended that if the topsoil is fairly deep (> 30cm), samples be collected from 0-15cm and also, if possible, 15-30cm. If, however, the topsoil is less than 30cm deep, a topsoil sample may be collected from the surface to as near as possible 20cm, and also from the upper 15cm of the subsoil. Thus, the actual depths samples are determined for each site according to the sequence of soil horizons, but once agreed upon should be adhered to throughout the plot and for future samples.

Soil samples may be collected from either small pits or auger borings, of which the former is to be preferred since they facilitate the observation of soil horizons. Soil should be collected in equal amounts from the entire range of the standard depth being samples, and not just from the middle of the range.

Individual soil properties can vary considerably over a relatively small area. Thus, samples collected from only one auger boring or pit can only be assumed to be representative of that one site, which may or may not be typical of the surrounding soil. Therefore, if a sample is required to reflect the chemical fertility of a field or block, soil should be collected from at least ten sites representative of the area being sampled. The ten samples (for any one standard depth) should be thoroughly mixed on a clean plastic sheet, and small portions taken at random until a subsample of about 500g is obtained.

Areas to be sampled should contain approximately uniform soils, avoiding irregularities such as mounds, depressions, former house or tree sites, post holes or areas where timber or rubbish has been burnt, or subsoil deposited e.g. alongside drains. Any undecomposed plant material should first be removed from the surface and samples collected from the coffee inter-rows.

It is also important to record the date when a soil sample was collected. The levels of some nutrients in the soil, particularly available nitrogen, can vary considerably from month to month in response to factors related to climatic conditions and the cropping cycle. It is good practice to always collect soil samples at the same time in the annual crop cycle, for

example, just before, and/or just after, the main harvesting period, which may vary from place to place and year to year.

The procedures for pretreatment of soil samples are also extremely important. Soil should be air-dried for two or three days, or oven-dried overnight at 30°C, before dispatch to the laboratory in clearly labelled plastic bags. Oven drying at higher temperatures should be avoided since this may influence some soil properties.

## A1.2 INTERPRETING SOIL ANALYTICAL DATA

Interpreting analytical results is not a simple matter. What may represent a deficiency under one set of environmental conditions, or at one particular time in the annual crop cycle, may not represent a deficiency under another set of conditions, or at another time in the crop cycle. Coffee exhibiting deficiency symptoms may not have deficient levels in the leaves. Despite high nutrient levels in the soil, coffee trees may still be deficient in certain nutrients, for example during very dry weather.

General guidelines for interpreting analytical data can be produced based on field trials and observations over a number of years. Such guidelines, particularly those for soil analyses, are not infallible, but they do provide a reasonable interpretation for the majority of samples.

To facilitate interpretation of analytical data, it is important that growers maintain accurate records of block histories, particularly details of fertiliser inputs and yields obtained.

**Table A1.1: Critical levels for interpretation of soil analytical data**

ANALYSIS	UNITS	VERY LOW	LOW	MEDIUM	HIGH	VERY HIGH
pH (H <sub>2</sub> O) <sup>(9)</sup>	pH	< 4.5	4.5-5.2	5.3-6.5	6.6-7.5	> 7.5
Total N	%	< 0.10	0.10-0.19	0.20-0.49	0.50-1.00	> 1.00
Organic C	%	< 2.0	2.0-3.9	4.0-9.9	10.0-20.0	> 20.0
Exch. K <sup>(1)</sup>	me/100g	< 0.10	0.10-0.19	0.20-0.59	0.60-1.20	> 1.20
Exch. Ca	me/100g	< 2.0	2.0-4.9	5.0-9.9	10.0-20.0	> 20.0
Exch. Mg	me/100g	< 0.3	0.3-0.5	0.6-0.9	1.0-6.0	> 6.0
Exch. Na	me/100g	< 0.10	0.10-0.29	0.30-0.69	0.70-2.00	> 2.0
CEC	me/100g	< 5	5-10	11-25	> 25	-
ECEC	me/100g	< 2	2-5	6-10	11-20	> 20
Base Satn.	%	< 10	10-19	20-60	> 60	-
Al Satn.	%	< 20	20-39	40-59	60-80	> 80 <sup>(2)</sup>
Avail. P	ug/ml	< 10	10-19	20-30	> 30	-
P Retn.	%	< 10	10-59	60-84	85-95	> 95
Reserve K <sup>(5)</sup>	me/100g	< 10	0.10-0.19	0.20-0.34	0.35-0.50	> 0.50
Reserve Mg <sup>(6)</sup>	me/100g	< 0.10	3.0-6.9	7.0-14.9	15.0-30.0	> 30.0
Soluble B <sup>(7)</sup>	ug/g	< 3.0	0.50-0.99	1.0-1.99	2.00-5.00	> 5.00
Sulphate-S <sup>(8)</sup>	ug/g	< 0.50	5-14	15-49	50-150	> 150
DTPA <sup>(3)</sup> Fe	ppm	< 4.5				-
DTPA <sup>(3)</sup> Mn	ppm	< 3.0				> 140 <sup>(4)</sup>
DTPA <sup>(3)</sup> Cu	ppm	< 0.6				> 11 <sup>(4)</sup>
DTPA <sup>(3)</sup> Zn	ppm	< 0.5				> 7 <sup>(4)</sup>

- Notes:
1. Exchangeable K should also represent at least 3% of total exchangeable bases.
  2. Al saturation greater than 80% is toxic to coffee.
  3. Determined in diethylene triamine pentacetic acid using the method of Lindsay and Norvell (1978). Figures are only tentative.
  4. Trace element contents in excess of these values may be toxic.
  5. Extracted in boiling nitric acid.
  6. Extracted in boiling 1M hydrochloric acid.
  7. Determined in hot water extract.
  8. Extracted with 0.04M calcium phosphate and the sulphur extract measured turbidimetrically following treatment with charcoal and an acid digestion to remove organic matter.
  9. Soil: water ration of 1:5 (but see also the assumption below).

In addition to Table 1, the following assumptions may also be used in interpreting analytical data:-

- pH values obtained using soil: water ratios of 1:1 or 1:2.5 may be simply converted for use in Table 1 by adding 0.5 or 0.3 pH units respectively. For data obtained from 0.01M CaCl<sub>2</sub>, or 1N KCl suspensions, 0.5 or 1.0 pH units should be added respectively.
- The normal range of values for the C:N ratio is 8-14, and indicates satisfactory rates of mineralisation of organic nitrogen.
- Ideal ranges for the ratios of bases are Ca:K < 20 and Mg:K < 10.





## **APPENDIX 2**

### **LEAF SAMPLES**

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#### **A2.1 HOW TO COLLECT LEAF SAMPLES**

Areas to be sampled should contain uniform soils and coffee of uniform age, variety, cultural practice and appearance. Typically, sampling sites should not exceed 3ha, although larger sites may be possible in very uniform areas.

The leaves collected should be the third pair from the tips of primary branches midway between the ground and the top of the tree. Two pairs of leaves should be taken from at least ten trees randomly selected in the area, to give a total sample of at least 40 leaves. Care should be taken to ensure that leaves are collected equally from all four quadrants (north, south, east and west) of trees. This is particularly important in unshaded coffee, where leaf nutrient levels have been shown to vary between quadrants.

A leaf should only be counted as such if it is over 5cm long. Branches containing large numbers of flowers or berries should be avoided.

As with soil sample collection, leaf samples should, if possible, always be collected at the same stage in the annual crop cycle each year. Leaf nutrient levels do vary considerably at different times of the annual crop cycle. Just before and/or just after the main harvesting period are appropriate times for leaf sampling, and it is good practice to collect both soil and leaf samples at the same time. Ideally, leaf samples should be collected before 10.00 hours.

Pretreatment procedures for leaf samples consist of sun drying for one or two days, or preferably, drying overnight in a forced convection oven at 60°C. Leaf samples should be dispatched to the laboratory in clearly labelled, brown paper bags.

#### **A2.2 INTERPRETING LEAF ANALYTICAL DATA**

The general comments on interpreting leaf analytical data are the same as those for interpreting soil analytical data.

**Table A2.1: Critical levels of nutrients in Arabica coffee leaves**

NUTRIENT	UNITS	DEFICIENT	SUBNORMAL	NORMAL	EXCESS
N	%	< 2.00	2.00-2.60	2.61-3.50	> 3.50
P	%	< 0.10	0.10-0.15	0.16-0.20	> 0.20
K	%	< 1.50	1.50-2.10	2.11-2.60	>2.60
Ca	%	< 0.40	0.40-0.75	0.76-1.50	> 1.50
Mg	%	< 0.10	0.10-0.25	0.26-0.40	> 0.40
S	%	< 0.10	0.10-0.15	0.16-0.25	> 0.25
Fe	ppm	< 40	40-70	71-200	> 200
Mn	ppm	< 25	25-50	51-100	> 100
Zn	ppm	< 10	10-15	16-30	> 30
Cu	ppm	< 3	3-7	8-20	> 20
B	ppm	< 25	25-40	41-90	> 90
Al	ppm				> 60
Mo	ppm	< 0.5	0.5-0.8		

## APPENDIX 3

### ANALYTICAL METHODS

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#### A3.1 SOIL ANALYSES

##### Sample Preparation

Air dried at 30°C for 2-3 days, then ground to pass through a 2mm sieve. Results expressed on air dried, sieved basis.

##### Soil pH

The pH of a 1:2.5 (v/v) soil-distilled water slurry is measured electrometrically, after sitting for 16 hours.

##### Total N

Kjeldahl digestion, without recovery of nitrates. A 1:20 (w/v) soil:concentrated sulphuric acid mixture is boiled with a selenium catalyst. The generated ammonium-N is determined colorimetrically using indophenol-blue.

##### Available P

The Olsen extraction, using 0.5M sodium bicarbonate at pH 8.5. A 1:20 (v/v) soil:bicarbonate mixture is used, with a 30 minute reciprocating shake. Extracted P is determined using the molybdenum blue colorimetric procedure.

##### Exchangeable K

Neutral, molar ammonium acetate extraction, using a 1:20 (v/v) soil:solution mixture, and a 30 minute reciprocating shake. Potassium in the filtrate is measured using atomic emission spectroscopy.

##### Exchangeable Mg

Neutral, molar ammonium acetate extraction, as for exchangeable K. Magnesium in filtrate is measured using atomic absorption spectroscopy.

##### Exchangeable Ca

Neutral, molar ammonium acetate extraction, as for exchangeable K. Calcium in the filtrate is measured using atomic emission spectroscopy.

##### Exchangeable Na

Neutral, molar ammonium acetate extraction, as for exchangeable K. Sodium in the filtrate is measured using atomic emission spectroscopy.

##### Cation Exchange Capacity

Calculated by summing exchangeable cations and titratable acidity of the ammonium acetate extract after extraction.

#### A3.2 LEAF ANALYSES

##### Sample Preparation

Leaf samples are dried overnight at 60°C until crisp, and ground. Results are reported on a dry matter basis.

**N**

A Kjeldahl semi-micro digestion in boiling concentrated sulphuric acid, assisted by hydrogen peroxide and a selenium catalyst. A 1:30 (w/v) dried leaf sample:concentrated sulphuric acid mixture is boiled for 2 hours. Generated ammonium-N is determined using indophenol-blue colorimetry.

**P**

0.2g of dried leaf sample is digested in a mixture of 2ml nitric acid and 1 ml perchloric acid. The digest is made up to 20 ml with distilled water, and the phosphorus in the digest is determined colorimetrically using Barton's agent (vanadomolybdate).

**K**

Digest prepared as for leaf P, and the potassium in the digest is determined by atomic emission spectroscopy.

**Mg**

Digest prepared as for leaf P, and the magnesium determined by atomic absorption spectroscopy.

**Ca**

Digest prepared as for leaf P, and the calcium determined by atomic absorption spectroscopy.

**Na**

Digest prepared as for leaf P, and the sodium determined by atomic emission spectroscopy.

**S**

Digest prepared as for leaf P, and the consequent sulphate determined as barium sulphate using turbidimetry.

**Fe**

Digest prepared as for leaf P, and the iron determined by atomic absorption spectroscopy.

**Mn**

Digest prepared as for leaf P, and the manganese determined by atomic absorption spectroscopy.

**Zn**

Digest prepared as for leaf P, and the zinc determined by atomic absorption spectroscopy.

**Cu**

Digest prepared as for leaf P, and the copper determined by atomic absorption spectroscopy.

**B**

Digest prepared as for leaf P, and boron determined colorimetrically following reaction with azomethine-H reagent.

## APPENDIX 4.

### COFFEE PARCHMENT STANDARDS, FACTORY STANDARDS AND EXPORT GRADES, 2016

#### A4.1. PARCHMENT STANDARDS

##### A4.1.1 Introduction

Parchment Arabica Coffee is defined as dry Arabica coffee beans wrapped in the endocarp. Coffee at the parchment stage of the processing chain is the most widely traded within the country. While it is primarily classified according to colour, quantitative measurements are possible, such as moisture content and number of defects.

The objective of parchment standards is to ensure that growers who take care in the preparation of their coffee have a basis to demand the highest price available on the day of sale. It also assists the buyer, factory manager or roadside trader, in price negotiation and should discourage habitual presentation of poor quality coffee on the market.

##### A4.1.2 Standards

PNG Standard 1626 : 2015 provides for three (3) classes of Arabica parchment as described in Table A4.1, classified on the basis of appearance and defect.

**Table A4.1 Standards for Arabica Parchment**

Parchment Class	Description	Maximum Defect allowed (per kg)
Class 1	Clean, sound, pale, even coloured Arabica parchment which is substantially free of visible defects, has no off odours and is capable of yielding either A or B grade green bean	10
Class 2	Clean, sound, pale coloured Arabica parchment, which has some visible defects and is capable of yielding Y grade green bean.	70
Class 3	Arabica parchment which does not have an excessive amount of visible defects and is capable of yielding Y2 grade green bean	150

##### A4.1.3 Definitions relating to parchment standards

a) Defects

All defects would have the same value and are defined as follows:

*“Coffee parchment beans which are not normal in physical appearance. Beans damaged by nature or insects or during processing”.*

The buyer should take as many samples as necessary and must calculate the defects on a per kg equivalence. **In these calculations all defects have a value of one (1).**

b) Foreign matter

Foreign matter is defined as: *Any substance not derived from the coffee cherry.*

Factories should reject all parchment with foreign matter. Any parchment containing foreign matter is immediately downgraded to Class 3. Class 3 also allows parchment that is substantially free from foreign matter.

#### **A4.1.4 Moisture**

Parchment is classified on the basis of appearance and number of defects. Moisture is treated separately and will have a significant impact on the price paid to the smallholder.

Moisture of the coffee is generally determined using the standard teeth and rubbing method. Managers should use their discretion in allocating an adjustment for moisture, since many factories prefer to purchase parchment at slightly higher moisture contents.

**Table A4.2: Moisture content of parchment**

<b>Moisture</b>	<b>Measure</b>
9-11% 'Machine Coffee'	Very hard. No teeth marks.
11-15%	Hard only slight marks with teeth.
15-20%	Soft black appearance. Easy to mark with teeth.
20-30%	Very soft black. Crushes with teeth.

The appropriate price adjustments should therefore be used and the appropriate level of price discounts should be applied.

Plastic laminated posters setting out the Classes of Parchment should be displayed near all buying points and in all factories.

The prices for all 3 Classes of parchment should be clearly displayed at buying points and at factory door.

## **A4.2. STANDARDS - EXPORT GRADES**

### **A4.2.1 Green bean grades and standards**

PNG Standard 1626 : 2015 provides specifications for Green Coffee in Papua New Guinea (PNG): standard parameters and criteria for liquor and physical quality: criteria for sampling, analysis, and determination of grades: specification for marking and packaging. The reader should refer to PNG Standard 1626 : 2015 for full details.

PNG Standard 1626 : 2015 provides for five (5) grade designations : A, B, Y, Y2 and Y3. Bean size of A, B and Y grades may be further classified with the use of a suffix. Details are shown here in Table A4.3

#### **A4.2.2 Export standards and packing for export**

Licensed factories are required to grade their coffee to the standard ready for export. PNG Standard 1626 : 2015 sets out clear guidelines for packing for export whether in bags or in bulk containers. The guidelines include details on bag labelling.

##### **A4.2.2.1 Packing in Bags**

- Green coffee for export shall be packed in clean, sound, new non-mineral oil, jute bags free from tears, any sign of leakage or any objectionable odour. Bags for export coffee shall be between 1020 and 1070mm long and between 535 and 610mm wide.
- Where coffee is packed in jute bags with water-resistant and hermetically sealable liners, random sampling shall be undertaken by authorized CIC Provincial Inspectors prior to packing and sealing the liner within clean, sound, new, non-mineral oil jute bags free from tears, any sign of leakage or any objectionable odour. Export and Quality assurance and certification must be undertaken and cleared in designated ports prior to export.
- The net weight of a bag of green coffee for export shall be 60 Kg at time of shipment, except for Y3 which may weigh less.

##### **A4.2.2.2 Export Bag Labelling**

Bags for export of green coffee shall bear the following markings in black indelible food-grade ink in letters not less than 50mm high and 6mm thick. The marks shall be placed in separate lines, centrally placed below the mouth or closure in the following order:

- a) The words "Papua New Guinea" or the initial "PNG",
- b) "Washed Raw Robusta Coffee" according to contents;
- c) The words "Clean, sound and new" denoting the condition of the bag;
- d) On the reverse side of the bag, the following marks shall be displayed in separate lines centrally placed in the following order;
  - i) A mark rectangle placed breadth wise below the mouth or closure of the bag and printed in black indelible food-grade ink so as to obscure any other markings required by this section. The rectangle to be divided into three compartments;
  - ii) Indelibly marked in black food-grade ink in figures not less than 50mm high the following shall appear within the three compartments;
  - iii) In the left-hand compartment the number 166 being the ICO identification mark for PNG;
  - iv) In the centre compartment a number up to four digits long allocated by the CIC to identify the exporter of the coffee;
  - v) In the right-hand compartment a number up to five digits long being the exporter's serial number for the particular lot of coffee.

Note: There are 10 additional instructions re labeling; the reader should refer to PNG Standard 1626 : 2015

#### A4.2.2.3 Packing in Bulk Containers

1. The green coffee shall be stuffed in a 20 foot Standard Ocean-Going Container. The bulk containers shall be clean, sound, dry, water and air tight, and must be free of any objectionable odour.
2. The containers shall be lined with clean and dry polythene or polypropylene liners that are free from tears, any signs of leakage and any objectionable odour.
3. The maximum net weight of green coffee in bulk containers shall not exceed 21,600 kg or 360 x 60kg green coffee bags equivalent. All bulk weights must be indicated clearly on every export document.
4. When bulking is completed, authorized CIC Inspectors shall issue an Inspection Certificate and may put its seal on the bulked container. The sealing is final and shall not be tampered with until it reaches the port of destination.
5. Unless otherwise stated, all bulk coffees should be shipped on FCL/FCL basis.

#### **A4.2.3 Drawing of Samples for Analysis**

PNG Standard 1626 : 2015 specifies that sampling for any purpose shall be carried out according to the provisions of ISO 4072 – Green Coffee in Bags – Sampling. Refer to PNG Standard 1626 : 2015 For details

#### **A4.2.4 Moisture Content**

PNG Standard 1626 : 2015 specifies that Green Coffee for export shall contain water at not less than 8% nor more than 12.5% of total mass. Determination may be made according to ISO 6673 or by another method agreed upon by the parties concerned.

#### **A4.2.5 Olifactory and Visual Examinations**

- 1) Examinations and Determination shall be made according to the provisions of ISO 4149
- 2) Allocation of Grade to sample being examined shall be made according to the specification Table A4.3 and A4.4

#### **A4.2.6 Sensory Analysis**

- 1) Samples for sensory analysis shall be prepared according to the provisions of ISO6668
- 2) Allocation of Grade to sample shall be made according to the specifications set out in Table A4.3 and A4.4

#### **A4.2.6 Size Analysis**

Size analysis shall be carried out according to the provisions of ISO 4150 and made according to the specifications set out in Table A4.3



**Table A4.3 : PNG Green Coffee Specifications for Arabica Coffee**

Grade	Cup Quality	Maximum Defect allowed (Equivalent per kg)	Raw Bean Colour	Odour	Bean Size																								
A	Full, reasonably balanced, uniform, clean, cup; well pronounced body and acidity; rich and distinct fragrance and aroma.	10	Bluish Green	Fresh and clean, no off odours allowed	Displayed as a Suffix. Where a specific screen size is designated the coffee must be uniform in size above designated screen size. No suffix means the coffee is mixed size.																								
B	Regular, uniform clean cup; medium to high acidity and pronounced body; rich fragrance and aroma.	30	Even, green to bluish green																										
Y	May lack some uniformity in the cup; good acidity and body; some fruitiness/ wineyness; good fragrance and aroma.	70	Pale green to green			Clean/ fresh, Some fruitiness																							
Y2	Irregular cup profile; fair acidity and body; no foul or foreign flavour.	150	Mixed light green to green			No foul or foreign odours.	Mixed																						
Y3	No foul or foreign flavour.	30% defects excluding good nipped beans. No foreign matter. Must be fit for human consumption.	Mixed			No Foul or foreign odours.	Mixed																						
							<table border="1"> <thead> <tr> <th>Screen No.</th> <th>Screen Diameter (mm)</th> <th>ISO norm</th> </tr> </thead> <tbody> <tr> <td>20</td> <td>7.94</td> <td>8.00</td> </tr> <tr> <td>19</td> <td>7.54</td> <td>7.50</td> </tr> <tr> <td>18</td> <td>7.14</td> <td>7.10</td> </tr> <tr> <td>17</td> <td>6.75</td> <td>6.70</td> </tr> <tr> <td>16</td> <td>6.35</td> <td>6.30</td> </tr> <tr> <td>15</td> <td>5.95</td> <td>6.00</td> </tr> <tr> <td>PB</td> <td>4.37 to 5.55 (single bean/ round shape)</td> <td>4.40 to 5.60</td> </tr> </tbody> </table>	Screen No.	Screen Diameter (mm)	ISO norm	20	7.94	8.00	19	7.54	7.50	18	7.14	7.10	17	6.75	6.70	16	6.35	6.30	15	5.95	6.00	PB
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PB	4.37 to 5.55 (single bean/ round shape)	4.40 to 5.60																											

**Table A4.4: Defect schedule**

Description of Defect	Number of Defect/ Foreign matter	Defect Equivalent
Large Stone (1 cm diameter)	1	2
Medium Stone (about 5 mm diameter)	1	1
Small Stone (less than 5 mm diameter)	3	1
Large Stick (3 cm length)	1	2
Medium Stick (2 cm length)	1	1
Small Stick (1 cm length)	3	1
Pod	1	1
Full Black	1	1
Partly Black	5	1
Full Sour	1	1
Partly Sour	5	1
Shells	5	1
Pulper-cut/Brokens	5	1
Floaters	5	1
White/Old	5	1
Parchment	2	1
Husk/Hull	2	1
Immature	5	1
Water Damage	5	1

NOTE: Any other foreign matter and defect not included in this schedule may be assessed by the authority using this standard or by an arbitration panel.