Summary

The African oil palm, Elaeis guineensis, is the major global vegetable oil crop.

Palm oil is consumed daily by over two billion people and can be found in about half of all products on sale in a typical supermarket.

Increased demand for palm oil, particularly in Asia and Europe, has led to extensive conversion of tropical habitats into plantations.

In some parts of Southeast Asia, this has had adverse ecological and environmental consequences that have led to calls for boycotts of products containing palm oil.

The industry is now responding to these pressures, albeit slowly and belatedly in some cases, and several schemes are in place to provide palm oil that is certified as being of sustainable origin.

Advanced breeding methods, particularly genomics, are beginning to bear fruit in terms of crop improvement for yield, quality, and biologically based pest and disease resistance.

In the future oil palm is set to become a truly global crop with important new centres of cultivation being developed in tropical Africa and the Americas.

Key words
palm oil, food, detergents, smallholders, plantations, peat soil, sustainability, advanced breeding, genomics, globalisation

Abbreviations
RSPO, Roundtable on Sustainable Palm Oil; HCS, High Carbon Stock; TILLING, TargetIng Local Lesions IN Genomes; CRISPR Clustered, Regularly Interspaced, Short Palindromic Repeats; TALENs Transcription Activator-Like Effector Nucleases; QTL, Quantitative Trait Loci

Introduction
Palm oil is obtained from the fruits of the African oil palm, Elaeis guineensis.

Oil palms originated in western Africa but are now grown in tropical regions around the world, most notably in Southeast Asia (see Table 1).

The fleshy mesocarp of the palm fruits produces a vitamin-rich oil that is a basic foodstuff consumed on a daily basis by over two billion people (1).

Palm oil is a particularly popular foodstuff in southern and eastern Asia where is it used for cooking and as a vegetable oil.
Palm fruits are produced in large bunches that hang from the foliage near the tops of the trees and can be harvested year-round (see Figure 1).

The major acyl components of palm mesocarp oil are oleic and palmitic acids, which makes it especially suitable for domestic and commercial cooking or frying applications.

The oil is also ideal for the manufacture of solid or semi-solid products such as margarines, creams or chocolate-type confectionary items including drinks and spreads (2,3).

For this reason, palm oil is used globally as an ingredient in numerous processed foods and confectionary items, such as ice cream, biscuits, cakes, chocolate, pizzas as well as in a host of ‘ready meal’ products.

Indeed, it has been estimated that palm oil is present in as much as half of all products on sale in a typical supermarket (2).

In addition to the edible oil from the fleshy mesocarp, the seeds, or kernels, of palm fruits contain a different type of oil that is enriched in medium-chain lauric and myristic fatty acids, which have many non-food uses.

For example, palm kernel oil provides the key functional constituents (i.e. lauric salts) in many cosmetics and cleaning products such as lipsticks, toothpaste, washing-up liquids, shower gels, shampoos, and laundry detergents to name but a few examples (1,2).

Due to the ease with which medium chain fatty acids are absorbed by the body, palm kernel oil, which is similar in acyl composition to coconut oil, is also used in specialised edible applications including some hospital foods, infant milk formula, and some sports nutrition products.

Why does palm oil have a poor reputation in some countries?
Despite its evident importance for human nutrition, health and hygiene, the oil palm sector has been subject to increasing vilification in some parts of the world over the past decade.

This had been mainly due to the perceived environmental and ecological impacts of some of the more recent oil palm plantations, especially in Indonesia, that have sometimes displaced pristine tropical habitats (4,5,6).

There has also been a perception that palm oil has negative nutritional qualities, despite it being an important human food product for millennia.

The poor perception of oil palm is hardly surprising because, over recent years, much of the media coverage of oil palm has included bleak images of displaced orang utan and other wildlife (7) alongside burning, degraded tropical forests producing huge amounts of pollution and the release of greenhouse gases (8,9).

This perception means that most people in the West have decidedly negative opinions about oil palm.

In contrast, some groups in Asia have questioned the motives of certain anti-palm NGOs, which they see a threatening a key aspect of economic growth in the region (10).

The major criticism of the oil palm industry relates to the expansion of cultivation that has sometimes (but by no means always) been at the expense of rainforest.

This expansion has been driven by increased demand for palm oil both in Asia and Europe.

After 2000, increased global demand for food (mainly from India and China) and for biofuels and other non-food products (mainly from Europe) were the major factors behind the conversion of land in Southeast Asia (mostly in Indonesia) to oil palm cultivation (see Table 2).

In Indonesia the area of oil palm cultivation more than trebled from 2.5 Mha (million hectares) to over 8 Mha between 2000 and 2014 (11).

In some cases this has led to significant habitat loss for iconic species such as orang utan that has triggered large decreases in local populations (7).

There have also been more general reductions in overall species biodiversity as complex ecosystems are replaced with simpler plantation systems that host fewer species (12).

In some quarters, oil palm is now characterised as an evil that needs to be removed from the landscape.

More recently there have been several well publicised anti-oil palm campaigns, especially in some Western countries.

In certain cases these have involved the organisation of consumer boycotts of oil palm products ranging from cosmetics to chocolate (13,14,15).

One example from June 2015, which involved an outspoken attack by the French minister of ecology, Ségolène Royal on a company using palm oil, although this was subsequently fully retracted, as described in Box 1.

In contrast to these negative views on oil palm, there is an increasing recognition that oil palm is a necessary crop that has many benefits, including supporting the livelihoods of millions of small farmers in Asia and Africa (17, 18).

Rather than boycotting palm oil products, therefore, there is a movement to certify that such products are only obtained from plantations that can verify that their oil has been produced using sustainable methods and was not sourced from areas recently converted from sensitive forest or peatland habitats.

The most important of these schemes is the Roundtable on Sustainable Palm Oil (RSPO) set up in the early 2000s) (19,20).

It is important to realise, therefore, that in contrast to the highly critical views on oil palm often heard in the West, there is another perspective on oil palm that is much less frequently heard.

This concerns an ancient and bountiful African tree crop whose fruits provide a wholesome, vitamin-rich oil that is an integral part of the diet of billions of people in 150 countries around the world (1).

It is about a crop that is cultivated by a complex and wide ranging agricultural sector that ranges from millions of smallholder farmers with tiny plots of a few dozen trees to less than a dozen very large multinational plantation companies each growing millions of trees.

While there are undoubtedly examples of poor practice in this vast and diverse industry, serious efforts are now underway to meet modern targets for environmental impact and overall sustainability.

History of oil palm as a crop

The African oil palm has been cultivated as a source of food and fibre by people in Western Africa for many thousands of years and was harvested by hunter gatherers for many millennia before then (21).

Oil palm fruits were highly prized and were traded across the continent from the Atlantic coast to the Red Sea.

For example, remnants of palm fruits have been found in vessels from an Egyptian First Dynasty tomb at Abydos dated to at least 5,000 years ago (22).

Until recent times, cultivation remained mainly confined to the centre of crop origin in the West and Central African coastal belt between Guinea/Liberia and northern Angola.

Additional cultivation is now found from 16° North in Senegal to 15° South in Angola, and eastwards to Zanzibar and Madagascar, but by far the best production levels are reached in the high rainfall areas between 7° North and South from the Equator (23).

In the 19th century, oil palm was brought from Africa to Southeast Asia by Dutch and British colonists. It was originally brought to Java as an ornamental plant by the Dutch in 1848 but its economic potential was soon recognised.

Seed selection in the Botanic Gardens of Singapore and Bogor and at the Deli Research Centre in Sumatra resulted in the development of commercial varieties of the crop that have been grown on an increasingly wide scale since the 1930s in what are now the nations of Malaysia and Indonesia.

Large-scale oil palm cultivation was first commercialised by British planters in Malaya, during the mid-twentieth century.

Following the fall in demand for natural rubber after the 1950s, many rubber plantations were converted to oil palm and much of the modern development of the crop has taken place in Malaysia since its independence in 1957 (23).

In 2006, oil palm became the most important source of vegetable oil in the world (24).

Today this former West African subsistence crop is a major export earner for Indonesia and Malaysia (23), which together account for 85% of total global production (see Table 1).

One of the major factors driving this increased palm oil production is the seemingly insatiable demand to supply the expanding populations of India and China (1,24, Table 2).

The 2.4 billion people in these two countries currently make up about 40% of the world population.

In addition to their increasing populations, these two nations are becoming more affluent and their higher standards of living are associated with increasing demands for vegetable oil (see Figure 2).

Oil palm is a uniquely productive product
The current average annual yield of useful oil from an oil palm plantation in Malaysia is about 3.7 t ha-1 (tonnes per hectare).

However, by improving the way the crop is managed and harvested, this yield can be almost doubled to over 6-7 t ha-1 on the more advanced commercial plantations (1).

The greater yield on well-managed plantations is due to such measures as replanting with the latest genetically improved tree varieties, rigorously reducing crop losses from attacks by pests and diseases, optimising harvesting methods and minimising spoilage during transport and storage, and using the latest technology in processing mills.

Even at current yields, on a per hectare basis, oil palm is 6-10 times more efficient at producing oil than comparable temperate oil crops such as rapeseed, soybean, olive and sunflower (1).

In addition to its high oil yield, it is also a much more efficient crop than its competitors in terms of the intensity of land management, harvesting and processing required.

For example, the annual oilseed crops require replanting each year, which involves regular disruption of the soil structure by ploughing.

This means that in oil palm plantations the soil structure, or rhizosphere, has a rich organic content and is less disrupted compared to temperate oil crops.

The temperate oilseed crops also require a brief but intensive annual period of harvesting and processing that often must be completed in a matter of days, whatever the weather. In contrast, an oil palm tree can be cultivated for 20-30 years without disturbing the soil.

Another advantage of oil palm is that, within a given plantation, harvesting and processing can take place on a continual year-round basis within a relatively predictable climatic regime that has far less seasonal fluctuation than in temperate regions.

This means that the workforce, machinery, and other assets can be employed on a continuous basis throughout the year, rather than for a single intensive period, as is the case for annual oil crops (1).

To draw an analogy with microbial biotechnology, oil palm husbandry resembles an efficient continuous culture system rather than the much less efficient batch-processing system represented by annual crop husbandry.

As well as having a competitive edge over the annual oilseed crops, oil palm is also more productive than other oil-bearing tree crops such as olive or coconut, which respectively yield oil at about 2.0 t ha-1 and 0.3 t ha-1.

Given that the annually cultivated oilseed crops grown in western countries only produce oil in the range of 0.5 – 1.5 t ha-1, it is clear that oil palm has significant potential, not only to satisfy the increasingly demanding markets for edible oil in

India and China, but also to act as a source of valuable non-food products for the global oleochemicals industry.

In addition, although the use of food crops for biodiesel has been rightly criticised (25-28), if it is really necessary to produce biodiesel in the short term, oil palm is by far the most efficient and least land-consuming crop that can be used (28, 29).

The total global production of palm oil in 2015 is estimated at about 72.6 Mt, made up of 65.2 Mt mesocarp oil and 7.4 Mt kernel oil (30).

As noted below improved breeding and management have the potential over the next few years to produce >50% increase in oil yield as a conservative estimate (1).

This would deliver an extra 35 Mt of edible oil available from the same area of land already in use for the crop, i.e. without the need to expand the area of cultivation.

In contrast, the same amount of oil from major temperate oilseed crops, such as soybean or oilseed rape, would require cultivation of an additional 30-50 Mha of prime farmland in Europe or the Americas.

This is 2-3 times the entire global area already occupied by oil palm plantations and such a vast area of land is simply unavailable in temperate regions.

Oil palm is grown both by smallholders and by large plantation companies
A common misconception about oil palm is that it is overwhelmingly a ‘big business' crop.

In fact, there are more than 3 million smallholders growing the crop, nearly all of whom farm individual family-owned plots.

In Indonesia, which is the largest oil palm producing country, smallholder plots account for 40% of the total crop area (31,32).

In terms of international trade, the medium to large commercial plantations are the dominant players and it is this sector that has been most active in joining RSPO or similar certification schemes.

However, the smallholder sector has played a vital role in the economic advancement of millions of relatively poor rural people who have been able to purchase modern goods and educate their children (see Figure 3).

Smallholders also have millions of votes and are therefore an important constituency in rural areas of Malaysia and Indonesia that governments ignore at their peril.

Unfortunately, most smallholders do not have the resources or economies of scale to match larger plantations and their crops are in general less efficiently managed with yields lower than the national average (33).

Another serious issue for smallholders throughout Southeast Asia is that they are either unaware and/or cannot afford to join sustainability certification schemes such as RSPO (34).

In general, most smallholders in the past have not had access to some of the best elite germplasm developed by commercial companies, and in many cases they simply buy uncertified seed from local merchants.

The decision on whether or not to replant new trees is problematic for smallholders as it means losing their income for as much as 5 years until the new trees produce fruit.

It is another 5 years before a good level of productivity is reached but these mature trees will then maintain good yields for two further decades before a decline sets in.

Many trees on smallholder plots are now well beyond their productive lifetime and are giving steadily decreasing yields.

National replanting schemes are therefore needed for the sake of the smallholders and the efficiency of the sector as a whole.

The Malaysian government is now addressing this problem by committing US$135 million to facilitate a national replanting programme that is particularly targeted at smallholders (35).

The government has estimated that 365,000 ha of mainly smallholder oil palms are 25-37 years old, which means that they are well beyond their normal productive lifetime.

The aim is to replace 100,000 ha of ageing oil palms per year by providing grants to smallholders for the replanting costs plus an annual allowance for the first two years of zero productivity.

It is hoped that the larger commercial plantations will also replant a further 100,000 ha yr-1 so that by 2018, over 1 Mha will have been replanted.

If this can be achieved, and with the assumption that new oil palms capable of 5-6 t ha-1 will be planted to replace the current ageing stock producing 2-3 t ha-1, this rate of replanting could result in an additional oil yield in the region of 3 Mt in Malaysia by 2020 (1).

This >10% increase in yield can be readily achieved without converting any new land to oil palm and by using currently available plant varieties.

In reality, as discussed below, much higher yielding varieties will soon be available from ongoing breeding programmes, so there is even greater potential to increase Malaysia palm oil yields in the coming years.

The replanting issue that is currently such an urgent problem in Malaysia will also eventually affect Indonesia, which is an even larger palm oil producer.

Many plantations in Indonesia were installed during a comparatively brief period about two decades ago, meaning that most of them will require replacement, and consequent loss of income for growers, at about the same time.

The situation in Indonesia will be exacerbated by the far larger proportion of oil palm cultivated by smallholders compared to Malaysia.

It is estimated that over the next decade as much as 500,000 ha yr-1 will require replanting in Indonesia (1).

It would therefore be prudent for the Indonesian government to use some of the considerable revenues it is now receiving from a buoyant palm oil market to set aside funds for a large-scale national replanting programme in the early 2020s.

Such a scheme, which would have a guaranteed bonus in generating higher oil yields, could also reduce future pressures to convert pristine habitats to oil palm plantations.

Failure to implement oil palm replanting will mean declining yields in the coming decade and, given the likelihood of continuing international demand for palm oil, impoverished smallholders might decide to embark on a new round of ecologically undesirable land conversion.

Role of Sustainable Palm Oil plantations

Over the past year or so the pendulum of informed opinion has started to swing away from a simplistic view of oil palm as being an unmitigated environmental scourge (see Box 1).

Instead a more nuanced approach is gradually emerging that recognises the genuine pros and cons of this bountiful tropical crop.

One of the most encouraging developments has been the establishment of RSPO as a robust and independent body to certify the environmental and social credentials of palm oil.

The RSPO vision is "transform the markets by making sustainable palm oil the norm".

As of mid-2015 the RSPO had over 2,000 members globally that represent 40% of the palm oil industry, covering all sectors of the global commodity supply chain.

An estimated 11.75 Mt of global palm oil is currently certified by RSPO and the total is increasing steadily by the year.

The RSPO scheme is by no means perfect, as pointed out by some NGOs (36), but more recently the scheme has been praised by other NGOs for its firm action in expelling members that do not conform to standards (37).

Unfortunately, some companies have ignored the scheme altogether, often citing high costs and the difficulties of maintaining and checking identity preservation of RSPO-certified batches of oil in what has hitherto been a commodity product.

The development of traceability methods and reliable assays of batch origin are important challenges in order to enable quality assurance of certified oil cargoes.

As we saw above, few smallholders can afford RSPO certification and this has led to the establishment of other schemes with lower thresholds, such as MSPO (38) or ISPO (39) in Malaysia and Indonesia respectively.

While these schemes have their merits in engaging producers, especially smallholders, who feel unable to qualify for RSPO (40), they run the risk of being regarded by some NGOs, palm oil users and consumers as being a sort of 'RSPO-lite' (41).

For this reason, the majority of large European palm oil importing companies, such as Nestle, Unilever, Ferrero, Loders Croklaan, plus many major plantation companies, such as Sime Darby, IOI and United Plantations, have already signed up to RSPO.

The UK government has set an ambitious goal of having 100% of edible palm oil imports as RSPO certified by the end of 2015.

To quote from a government-commissioned report: "Many major UK and international businesses that use or sell palm oil have made commitments to 100% sourcing of sustainable palm oil by a given deadline, generally 2015." (42).

Similar commitments have been made by the governments of Belgium and the Netherlands (20).

Most people would agree that, whatever its limitations, RSPO probably represents the best vehicle currently available for the sustainability of palm oil.

This is especially true for large-scale producers and major users in the food and cosmetics industries, where their consumers can be sensitive to the eco-environmental credentials of such products.

For example, while one cosmetics retailer (Lush) has boycotted palm oil (resulting in considerable problems in sourcing alternatives), another retailer (Body Shop) has used 100% RSPO certified palm oil since 2011.

Assessing environmental impact and sustainability

One of the most important limitations in developing robust policies for a sustainable and environmentally sound oil palm industry is a lack of hard facts about the precise eco-social impacts of palm oil production and utilisation from 'cradle to grave'.

As an example, the following quote is from a 2015 study on ecosystem services provided by oil palm plantations:

"Our review highlights numerous research gaps. In particular, there are significant gaps with respect to information functions (socio-cultural functions). There is a need for empirical data on the importance of spatial and temporal scales, such as the differences between plantations in different environments, of different sizes, and of different ages. Finally, more research is needed on developing management practices that can off-set the losses of ecosystem functions." (43).

Scientific studies of the environmental and socio-economic impacts of oil palm are in their infancy and are fraught with problems due to the huge breadth, complexity, and interdisciplinary nature of the systems involved.

These already formidable challenges can be exacerbated by the roles of vested interests from all sides of the debate who will often cherry pick partial data from selected studies in order to back their already entrenched views.

In order to be credible, therefore, studies on oil palm sustainability should be performed by independent researchers and the results published in full, preferably in peer reviewed international scientific journals.

Moreover, such studies should not only focus on oil palm, but should carry out similar assessments of other oil crops in order to compile a comparative balance sheet of the various plus and minus points of other cropping systems, e.g. soybean or rapeseed, in the context of impact and sustainability.

One of the major tools for such a process that is much used by policymakers is life cycle assessment (LCA).

This method seeks to estimate the impact of all aspects of the production process from planting seed, growing, harvesting and processing the crop (including fuel and labour costs); application of inputs such as water, fertiliser, herbicides, pesticides etc; shipping of the oil overseas and its downstream conversion into other products including foods and oleochemicals; transport to wholesalers, retailers, and consumers; and finally disposal of all products at the end of their lifetimes.

These are only a few of the dozens of parameters involved in a comprehensive LCA and very few published studies manage to cover the entire system.

Despite these caveats and limitations, some useful LCA data are now emerging where oil palm is compared with some of the other major oil crops.

An example is a 2015 study, which shows that overall impact of oil palm, as determined by LCA methods, is comparable, and sometimes superior to the temperate crops (44).

Many more such studies are needed in order to inform better public debate and future policy about the true environmental impacts of oil crops.

Ecological and climate-related studies

During the past few years there has been a welcome increase in research on the comparative ecology of oil palm plantations, the impacts of land-use change, and the possible effects in relation to climate change, including a balance sheet for greenhouse gas emissions during conversion of forest or peatland to plantations.

There is insufficient space here to discuss all of these studies but a few examples will now be outlined.

The High Carbon Stock (HCS) Science Study was set up by five major oil palm growers (Asian Agri, IOI Corporation Berhad, Kuala Lumpur Kepong Berhad, Musim Mas Group, and Sime Darby Plantation), together with Cargill and Unilever, to increase their commitment to sustainable palm oil (45).

This group, which is jointly chaired by the academic, John Raison, and well-known environmentalist, Jonathon Porrritt, issued a draft report for discussion in 2015, in which they produce values for various environmental impacts and list a series of recommendations for future conduct of the industry (46).

Two other recent studies examine the potential impact of land use and climate change on biodiversity in Borneo where a great deal of oil palm planting has occurred (47,48).

The conclusions include the need to establish nature reserves in upland areas where climate change will be less severe and also to improve connections between reserves and plantations via wildlife corridors.

One of the most controversial aspects of new palm cultivation is the use of tropical peatland, especially in Borneo.

There are several ongoing studies of the impact of peatland conversion in terms of greenhouse gas emissions (49-55).

However, more studies by independent groups will be necessary in order to generate sufficient data for a meta-analysis that could provide robust policy options for the exploitation (or not) of peat soils.

Other studies, including a systematic analysis of tropical peat soils (56), have demonstrated an unexpectedly complex picture with several different categories of peat (see Figure 4), some of which can readily support oil palm crops while other types cannot (see Figure 5).

The conclusion is that it is not appropriate to impose blanket bans on the use of peat soils for oil palm cultivation but rather to survey the soil first before making a better informed decision (see Figure 6).

Investing in modern breeding and crop management

Plant breeding is a cornerstone of crop improvement, as shown by the Green Revolution of the 1960s and 1970s that successfully averted the spectre of famine in many developing countries (57).

During the 1980s and 1990s, advanced breeding methods, such as hybrid creation, assisted crosses and introgression of wild germplasm, were instrumental in enabling rice yield to increase five-fold in some regions of Asia.

During the 2000s, much attention has been focussed on genomic approaches to plant breeding with the deployment of a new generation of technologies, such as DNA marker-assisted selection, genome sequencing, transgenesis (genetic engineering or GM) and automatic mutagenesis/selection (TILLING, TargetIng Local Lesions IN Genomes) (57).

More recently new genome editing technologies such as the CRISPR (Clustered, Regularly Interspaced, Short Palindromic Repeats) and TALENs (Transcription Activator-Like Effector Nucleases) are showing even more promise for crop and livestock improvement (58-61). In 2015, the CRISPR/Cas9 system was described in a Nature article as “the biggest game changer to hit biology since PCR” (62).

All of the above methods have considerable potential for oil palm improvement and one of the most encouraging features of recent years is the development of systems to underpin future breeding efforts.

A key achievement has been the development of genomics and related ‘omic technologies by oil palm researchers (1).

These efforts culminated in July 2013 when the journal Nature published two back-to-back papers that described the sequencing of the genomes of two related oil palm species, E. guineensis and E. oleifera plus the associated discovery of the Shell gene that regulates fruit thickness (63,64).

Thin shelled fruits, as found in tenera hybrids, are high oil yielding and are now the basis for all commercial oil palm production in South-east Asia.

Identification of the Shell gene will enable breeders to use molecular markers to select suitable breeding lines, instead of waiting three to four years or more for the young plants to produce fruits for selection via a visual phenotype.

This notable achievement was followed in September 2015 by a further Nature paper reporting the identification of the epigenetic mechanisms that underlie the serious ‘mantling’ problem that has bedevilled efforts to use clonal propagation in the industry (65).

As with some other tree crops, tissue culture and micropropagation are often the best way to produce thousands or even millions of clonal copies of selected elite individuals.

Unfortunately, in the case of oil palm, epigenetic abnormalities regularly arise during tissue culture but it can take several years before the resultant deformed or ‘mantled’ fruits can be observed.

This has cost the industry millions of dollars and much wasted time in growing useless trees. The elucidation of the ‘mantled’ trait will allow for much earlier detection and elimination of affected trees and will therefore contribute to raising overall oil yield in the industry (66).

Oil palm breeders are also using advanced selection methods, including genetic markers based on DNA sequences, to assist in the selection of favourable agronomic traits.

Other modern techniques like association genetics and quantitative trait loci (QTL) analysis are also enabling chromosomal regions and individual genes involved in the regulation of important traits to be mapped and identified (57).

These methods have recently been used to map the lipase gene involved in oil deterioration in ripe palm fruits (67) and QTL analysis of genes regulating the fatty acid composition of palm oil (68).

Bioinformatic and 'omics methods are being used to annotate the oil palm genome and to discover genes involved in the regulation of key traits such as oil yield and quality, semi-dwarf trees and pest/disease resistance (69-72) (see Figures 7 & 8).

Efforts are also underway to breed high-oleic varieties of oil palm.

These varieties could compete with oilseeds, such as sunflower and rapeseed, both for premium edible markets and as feedstocks for medium-value oleochemicals such as lubricating oils (1).

The future of oil palm in Southeast Asia

Although, it should be possible to produce a lot more palm oil by increasing the crop yield, it seems inevitable that, at least in the short-term, some additional land conversion will be necessary (1).

There are several drivers for the continued expansion of demand for palm oil in the medium to long-term future, the most important of which population growth and economic progress in many developing countries.

In 2015, a global area of about 16 Mha produced 72.6 Mt of palm mesocarp + kernel oils.

Forecasting future levels of demand for any commodity is always challenging, but the following estimates from several reliable sources predict that about 77 Mt palm oil will be required by 2018 (73); 84 Mt by 2020 (74); and between 93 and 156 Mt by 2050 (19).

This is a formidable challenge but one that is achievable by a judicious mixture of management improvements, replanting better genetic stock, and some expansion of cultivation into other parts of the tropics.

Providing any new cultivation is carried out in an environmentally responsible manner, there are benefits from diversifying oil palm cultivation into other regions of the world.

For example, a more dispersed cropping area will be more resilient to threats from climatic factors or locally adapted pests and pathogens.

In this respect, the current concentration of >85% of global palm cultivation in one geographical area Malaysia/Indonesia) is far from ideal.

The expansion of cultivation into suitable areas of West Africa and South/Central America that is now underway will create a more secure production system in the longer term.

It is also worth pointing out that, as shown in Figure 9, none of these regions comes close matching to the cropping intensities already adopted in large parts of the USA and Europe.

Some of these measures could have a significant impact on output within the next five years.

For example, if the planned replanting programme in Malaysia (see above) is carried out, it could deliver an additional annual yield of 5 Mt palm oil on existing land.

If some of the best existing experimental breeding material, theoretically yielding 8-10 t ha-1, could be developed for commercial planting throughout the sector then yield could be increased by 50% or more.

This could deliver as much as 30 Mt more oil per year – again without requiring further land conversion.

Further into the future, there is the prospect of additional yield gains by using modern breeding technologies to produce fruits with a higher oil content and dwarf oil palms that bear more fruit and are easier to harvest mechanically.

At present, we cannot quantify the benefits of such biological innovations but they could potentially deliver tens of millions of tonnes of additional oil.

The future of oil palm in Africa and the Americas

In recent years there has been significant expansion of oil palm cultivation in Africa and the Americas.

Currently, the three major centres of cultivation in Central/South America are Colombia, Ecuador and Honduras with a modest annual output of 2 Mt oil.

According to IIASA estimates, these three countries and Peru have some potential to expand cultivation but by far the largest new prospective area is in Brazil.

Oil palm is more suitable as a crop in low elevation regions in the humid tropics and can even tolerate the highly acidic non-forest soils of Amazonia (75).

In Brazil, an estimated 32 Mha (excluding rainforest) are suitable for oil palm production (76), which is double the entire global oil palm area at present. It should be stressed that the vast majority of this possible expansion into oil palm in South America would be on grassland or planted pasture with very little, if any, forest conversion (77).

Conversion of such land would therefore have a lower impact on biodiversity and other sensitive environmental indicators that the conversion of tropical forest.

West Africa is the historical home of the commercial oil palm and, prior to the 1960s, Nigeria was a globally dominant producer.

Since then, civil conflict plus poor investment and management of the largely smallholder dominated industry led to a sharp decline in palm oil production.

By 2000, Nigeria was unable even to meet local demand and the country is now a net importer of edible oils (78).

However, the buoyant international demand for palm oil is stimulating the replanting of disused plantations or establishment of new plantations in several parts of West and Central Africa (79).

Much of this expansion will be required just to meet local requirements for vegetable oil.

For example, in 2010, Africa imported 2.4 Mt palm oil, mostly from Malaysia.

It is estimated that 24 Mha is suitable for growing oil palm in Nigeria alone (80).

In terms of climate and agronomy, another promising region for new oil palm cultivation in Africa is in the Congo River basin (81) and plantation companies are also steadily acquiring land in this and other parts of Africa (82).

Conclusions

The oil palm industry faces many challenges in the future.

However, the tools to surmount these challenges already exist and have the potential to further transform this historic crop into a truly global source of nutritious food and valuable non-food products for the growing world population.

Higher yielding cultivars with improved oil compositions and greater resistance to pests and diseases will be available.

We can also look forward to an extension of oil palm cultivation in new areas of the tropics.

Over the next decade, West and Central Africa will begin to emerge alongside Central/ South America as major producers of palm oil, initially for local consumption but eventually for export to global markets.

Between them, West/Central Africa and Central/South America have the capacity to convert well over 30-40 Mha to oil palm with a current yield potential of 130- 170 Mt oil, and much more than that if the expected increases in crop yields are realised.

It is highly unlikely that such a vast area, which is more than double the present oil palm area, will need to be converted.

However, even if only a quarter of this land is changed to oil palm plantations, these regions could be producing as much as 50-60 Mt oil by 2025.

This is close to the present global total and demonstrates that a doubling of palm oil production in the next few decades is quite feasible.

A redesign of plant architecture, especially the breeding of shorter stem, can further increase yields as well as transforming the management and processing of the crop.

If these and other genetic improvements and management efficiencies can be achieved, the resulting increased palm oil output could more than meet even the highest projections for future vegetable oil requirements.

Moreover, given its superior yield and land-use efficiency, oil palm might eventually displace some of the less efficient temperate oilseed crops as the preferred source of oil for many edible and non-edible markets.

Policy Proposals

The oil palm industry faces many challenges regarding its environmental credentials.

These challenges are common to all regions and companies with little differentiation among the general public between 'good' and 'bad' sources of palm oil.

Therefore the entire sector tends to be stigmatised by poor practice in a few areas.

It is highly desirable that this huge global industry, which is worth over US$50 billion annually, should collectively redouble its efforts to address sustainability and public image issues as a matter of priority.

One way to meet such challenges would be to form a global industry-wide body to facilitate best practice.

The remit of such a body could include:

Sponsoring independent research across the various disciplines related to the sector. Specific R&D areas might include yield and oil quality, pest/disease resistance, addressing management-related issues such as ecological and environmental impact, product image, tree replanting, labour supply and mechanisation.

Engaging independent experts in order to improve communications with NGOs and engage more effectively in a constructive dialogue with the general public.

Development of robust methods to validate sustainably certified palm oil. As certified palm oil (e.g. via RSPO) becomes increasingly common it will be necessary to validate the provenance of such oil in order to reassure end users, including household consumers. The development of reliable traceability protocols and verification methods for batch origin (as already done for olive oil) are important challenges in order to enable quality assurance of certified palm oil cargoes.

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Comments