interactions between stand structures and desired outputs mean that managers will need to be certain which are the key species, values, and products which their forests are to provide. They can then propose how such outputs will be affected by changes in stand structure achieved through silviculture, decide which mix of interventions is most appropriate, carry these out, and monitor the results after a suitable time interval. The silvicultural prescriptions may then be changed as a result of the information provided by the monitoring.
5. This highlights the need for decision support tools that are capable of simulating the development of stands under contrasting management regimes and that can be linked via a geographic information system (GIS) to show the flow of benefits over space and time from particular strategies. For instance, widespread adoption of a selection system might produce stands that were very heterogeneous at a small scale, but a landscape that was monotonous and where species dependent upon the stand initiation phase were underrepresented. Better understanding of how different benefits are influenced by stand structure is important here since silvicultural interventions seek to provide those structures that are thought to fulfill management objectives. Criteria for success in even-aged plantation management are well researched and described for many forest types in the world, but equivalent aids for multiple-use silviculture are rare.

In the last analysis, successful implementation of multiple-use silviculture requires the development of a shared future vision for a forest that can be used to inspire the public, employees, and various stakeholders. In areas such as the British Isles where the area of native woodland is small and fragmented, it is unrealistic to expect the native woods to provide the social and environmental benefits while the considerably more extensive area of plantation forests is managed largely as a wood factory. Instead, the plantation forests have to be diversified through multiple-use silviculture to provide the mix of benefits required by commitments to sustainable forest management. The challenge for foresters in such situations is not whether to adopt multiple-use silviculture, but rather how to do it and where best to begin the process.

See also: **Biodiversity**: Plant Diversity in Forests. **Ecology**: Natural Disturbance in Forest Environments; Plant-Animal Interactions in Forest Ecosystems; Reproductive Ecology of Forest Trees. **Genetics and Genetic Resources**: Forest Management for Conservation. **Landscape and Planning**: Forest Amenity Planning Approaches; Landscape Ecology, Use and Application in Forestry. **Recreation**: User Needs and Preferences. **Silviculture**: Natural Stand Regeneration. **Social and Collaborative Forestry**: Social Values of Forests.

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Sustainability of Forest Plantations

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Introduction

Plantation Forests

The present extent of planted forests worldwide probably exceeds 180 million ha. New planting in both tropical and temperate regions is leading to a significant net increase of forest plantation each year. It is predicted that in time a greater proportion of industrial wood will be sourced from plantations than from exploiting natural forests, and that this trend towards increasing reliance on planted forest for wood production will continue. Thus forest plantations appear set to become a major, even dominant, form of forest development. But as a way of growing trees, is it sustainable?

Sustainability

The concept of sustainability in plantation forestry may be considered to have two components. There are the general or broad issues of sustainability – so clearly articulated and placed on the international agenda in the 1980s by the Brundtland commission – of whether, in the case of tree plantations, using land and devoting resources to them is a sustainable activity from the economic, from the environmental, or from the social sense. Is such development unsustainable because it is economically questionable, or environmentally damaging, or a threat rather than a help to people's livelihoods and way of life and lead to alienation? The same questions may be increasingly asked about sustainable agriculture. Each of these, and related issues, are important in their own right and fundamentally depend on national policies governing plantation development, understanding their impacts, and ensuring full public participation in the process. They concern the concept of 'sustainable livelihoods' as a crucial dimension of the grand aim to eliminate world poverty by 2030.

An example in the case of plantations and sustainable environmental impacts is that it is generally accepted that plantations should not be established on land obtained simply by clearing natural forest formations. There is plenty of already degraded land resulting from past clearance or poor farming practices and which is of no importance for conservation, but will grow trees well: indeed, plantations can help restore degraded land. Thus plantations should not conflict with natural forest but be complementary to them. These and other issues relate to what can be labeled 'broad-sense' sustainability.

The second issue to do with sustainability concerns the practice of plantation silviculture itself. Is growing trees in plantations a technology that can work in the long term? Is such silviculture ecologically sound or are there inherent flaws which will eventually lead to declining growth rates as plantation crop succeeds plantation crop? This is what is meant by 'narrow-sense' sustainability and is the subject of this article.

'Narrow-Sense' Sustainability

The question raised is: can tree plantations be grown indefinitely for rotation after rotation on the same site without serious risk to their health and rate of growth? More specifically, can their long-term productivity be assured, or will it eventually decline

Figure 1 Litter raking beneath *Pinus caribaea* in southern China. This regular removal of needles, twigs, and branches intempts the nutrient cycle.

over time? Are some sites or forest crops more at risk than others and is this influenced by how they are managed? These questions are pertinent, owing to the increasing reliance on planted forests, but are also scientifically challenging since in previous centuries trees and woodlands were seen as soil improvers and not impoverishers. Are today's silvicultural and management practices more damaging because of greater intensity, such as clonal plantations, optimizing stocking levels, and harvesting on short rotations, which lead to high timber yields typically two to five times that of natural forest increment? Furthermore, are the use of tree-breeding programs, refined fertilizer treatment, more sophisticated manipulation of stand density and so on likely to lead to even more productive forest crops with time, or could they mask evidence of genuine site degrade or increasing risk of damaging pests and diseases?

Understanding sustainability also applies to nonindustrial uses. Sustaining the numerous benefits people derive from plantations should be a top priority and arise out of good management. Does the perpetual gathering and removal of leaves, twigs, and litter from beneath tree stands, so widespread in India and China, for example (**Figure 1**), simply loot the site of nutrients? And what of the flow of nontimber products, often of more value than wood, and perhaps less directly damaging to sites when harvested? These are relevant to plantation forestry, even if it is not always possible to answer such questions adequately.

Evidence of Productivity Change

Productivity Change in Successive Forest Rotations

Problems with data For forest stands (crops) firm evidence of productivity change over successive rotations is meager with few reliable data. Compared with agriculture, the long cycles in forestry make data collection difficult. Records have rarely been maintained from one rotation to the next or have simply been lost; funding for such long-term monitoring is often a low research priority; measurement conventions and even practices change which confound ready comparison; detection of small changes is difficult; and often the exact location of sample plots is inadequately recorded. In addition, because few forest plantations are second-rotation, and even fewer third- or later-rotation, even the opportunity to collect data has been limited. Unfortunately without data it is difficult to demonstrate whether plantation silviculture is robust and so refute (or otherwise) claims that successive rotations of fast-growing trees inevitably lead, for example, to soil deterioration.

Review of Evidence Comparing Yields in Successive Rotations

Over the last 100 years there have been six main reports that have thrown into question the sustainability of plantations over successive rotations. They are grouped here by region.

Spruce in Saxony and other European evidence In the 1920s reports began to emerge suggesting that significant areas of second- and third-rotation spruce (*Picea abies*) in lower Saxony (Germany) were growing poorly and showed symptoms of ill-health. There was a fall of two quality classes in second- and third-rotation stands, but this was only recorded over 8% of the plantation area. This became a much researched decline and was attributed to insect defoliation, air pollution, the effects of monoculture, drought, and simply the intensive forms of forestry practiced. It is now clear that much of the problem arose from planting spruce on sites to which it was ill-suited, to litter raking that depleted soil of nutrients, and planting on degraded agricultural land. Later studies, that included other sites, showed that growth of spruce was unchanged from rotation to rotation or even increased. Today young stands of pure spruce in Saxony and Thuringia appear to be growing more vigorously than equivalent stands 50 or 100 years ago.

Elsewhere in Europe reports of productivity comparing first and second rotation are limited. In Denmark no great change has been observed for Norway spruce crops but for beech (*Fagus sylvatica*) second-rotation productivity is reported as significantly better. In the Netherlands growth of second-rotation forest is generally 30% faster than the first where it has been assessed. Similarly, in Sweden second-rotation Norway spruce shows superior growth. In France some decline was reported from successive rotations of *Pinus pinaster* in the Landes, though this is not attributed to site deterioration. In the UK most second-rotation crops are equal to or better than the previous rotation and, in the case of restocking of Sitka spruce (*Picea sitchensis*), there is no requirement to reapply phosphate fertilizer which had been essential for establishing the original crop.

***Pinus radiata* in Australia and New Zealand** Reports of significant yield decline in second-rotation *Pinus radiata* emerged in South Australia in the early 1960s and by the end of that decade fall-off in productivity of about 30% affected most pine plantations in the state. These reports were alarming and generated a great deal of research into possible causes. By 1990 it had become clear for South Australia that harvesting and site preparation practices which failed to conserve organic matter, and an influx of weeds in the second rotation, especially massive growth of grasses, were the main culprits. With more sensitive treatment of a site, conservation of organic matter, and good weed control the decline problem was eliminated. With the additional use of genetically superior stock, growth of second- and third-rotation pine became substantially superior to the first crop, a situation which now prevails throughout the state. Indeed, a substantial proportion of the second and third rotation has been upgraded from low site qualities (mean annual increments (MAIs) 13–18 $m^3 ha^{-1} year^{-1}$) to high (MAIs 25–33 $m^3 ha^{-1} year^{-1}$).

In the state of Victoria the yield of second-rotation *P. radiata* is equal or superior to that of the first rotation and in New South Wales basal area and volume per hectare increases of 13 and 18% respectively are reported in the second rotation. In Queensland a careful study of first- and second-rotation *P. elliottii* of the same seed origin shows no evidence of yield decline, but a 17% increase in volume per hectare at 9 years where organic matter was left undisturbed.

In parts of New Zealand, on a few impoverished ridge sites in the Nelson area, there were signs in the 1960s and 1970s, albeit transitory, of yield decline. Today, as with plantations in Australia, holistic management and genetic improvement lead to yield gains from one rotation to the next.

Pines in Swaziland and South Africa Long-term productivity research by the writer in the extensive industrial pine plantations of the Usutu forest, Swaziland, began in 1968 as a direct consequence of the reports from South Australia about second-rotation decline. For 35 years measurements have been made over four successive rotations of *P. patula*, grown for pulpwood, from a forest-wide network of long-term productivity plots (**Figure 2**). Plots have not received favored treatment, but subject to normal forest operations, and tree growth simply measured and recorded during each successive crop.

Over most of the forest, where granite-derived soils occur, third-rotation height growth is significantly superior to second and volume per hectare almost so. There had been little difference between the first and second rotations. On a small part of the forest (about 13% of area), on phosphate-poor soils derived from very slow-weathering gabbro, a significant decline had occurred between first and second rotation, but this has not continued into the third rotation, where there is no significant difference between rotations. Fourth-rotation measurements are currently ongoing and initial results suggest it is growing better than all previous rotations: there is certainly no evidence of decline.

The importance of the Swaziland data, apart from the long-term nature of the research, is that no fertilizer addition or other ameliorative treatment has been applied to any long-term productivity plot from one rotation to the next. Although some third-rotation *P. patula* is probably genetically superior to the second rotation, this effect is small and more than compensated for by the severe drought in the period 1989–1992 which will have adversely impacted third-rotation growth. These data are also of interest because plantation silviculture practiced in the Usutu forest over some 72 000 ha is intensive, with pine grown in monoculture at stockings of 1100–1500 stems per hectare, never thinned, and on a rotation of 15–17 years, which is close to the age of maximum MAI. The limited genetic improvement of some of the third rotation could have disguised a small decline, but evidence is weak since breeding generally improves net primary productivity (NPP), which cannot be realized if one or more nutrients is deficient. Also, it can be strongly argued that without the severe and abnormal drought, growth would have been even better than it is. The current indications of improved fourth-rotation growth probably reflect the impact of genetic improvement. Overall, the Swaziland evidence suggests no serious concern over narrow-sense sustainability.

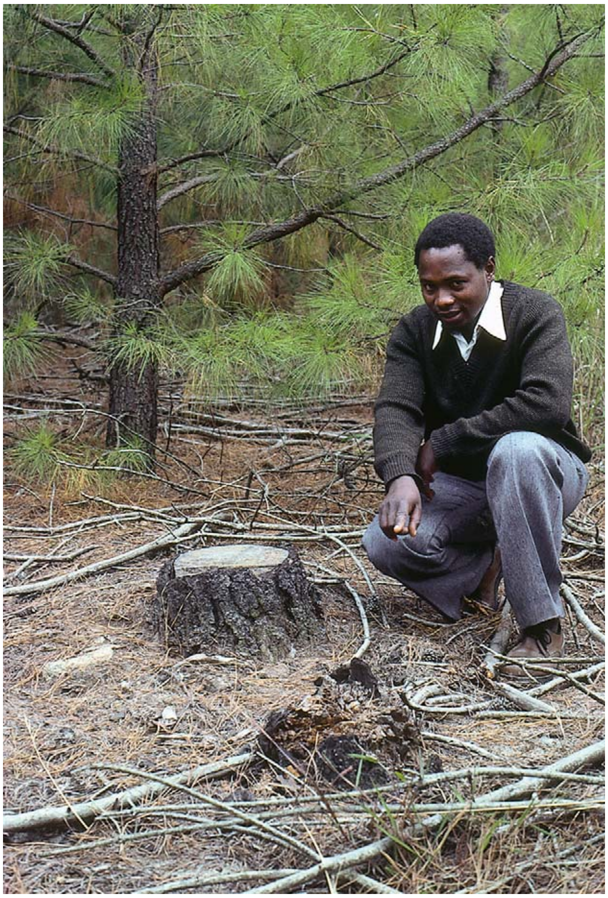

Figure 2 Signs of three rotations in the Usutu forest, Swaziland, photographed in 1986. Old first-rotation stump (indicated), second-rotation stump cut 6 years ago, and third-rotation stand in background. This site now supports a fourth-rotation stand of pine which is growing better than the three previous rotations.

In South Africa there is no evidence of productivity decline over successive rotations other than localized small-scale examples arising from compacted soil. Excessive accumulation of undecomposed litter in some high-altitude stands of *P. patula* does give rise to concern over increasing soil acidity and nutrient immobilization. In wattle (*Acacia mearnsii*) crops grown intensively for their bark for tannin production, there is no evidence of yield decline with successive rotations.

Chinese fir in subtropical China About 6 million hectares of plantations of Chinese fir (*Cunninghamia lanceolata*) have been established in subtropical China. Most are monocultures and are worked on short rotations to produce small poles. Foliage, bark, and sometimes roots are all harvested for local use. Reports of significant yield decline have a long history. Typically there is a drop in productivity between first and second rotation of about 10% and between second and third rotation of up to a further 40%. Chinese forest scientists attach much importance to the problem and pursue research into monoculture, allelopathy, and detailed study of soil changes. However, it is clear that the widespread practices of whole-tree harvesting, total removal of all organic matter from a site, and intensive soil cultivation that favors bamboo and grass invasion all contribute substantially to the problem.

Teak in India and Java In the 1930s some evidence suggested that replanted teak (*Tectona grandis*) crops (second rotation) were not growing well in India and Java. Although significant soil erosion is widespread under teak and organic matter is frequently lost as leaves are burnt, research into the 'pure teak problem,' as it was called, did not generally confirm a second-rotation problem. Site deterioration under teak does often occur with yields from plantations not coming up to expectation but causes are mainly management-related, namely poor supervision of plantation establishment, overintensive taungya (intercropping) cultivation, delayed planting, and poor aftercare. There are few data from successive rotations – the ideal way of evaluating changes in productivity – since teak rotations are long, typically 50–80 years.

Southern pines in the USA Plantations of slash (*P. elliottii*) and loblolly (*P. taeda*) pines are extensive in the southern states. Significant planting began in the mid-1930s as natural stands were logged out .With rotations usually about 30 years, restocking first began in the 1970s. The growth of this second rotation appears variable, with reports of both better and poorer growth. Changes between rotation are attributed to differences in site preparation and to competition from understory shrubs and weeds. Where weeds are well controlled and appropriate site preparation used, such as a bedding plough, growth is often superior. Genetically improved stock and use of fertilizers are expected to bring further increases.

Within-Rotation Yield Class/Site Quality Drift

The recently observed phenomenon of yield class or site quality change with time has two aspects – change between predicted and actual yield over time, and correlation of site quality (yield class) with date of planting rather than just site fertility.

Inaccuracy in predicted yield For long-rotation (>20 years) crops it is usual to estimate yield potential from an interim assessment of growth rate early in life and then to allocate a stand to a site quality or yield class. This is a good way of forecasting likely yields overall, though imprecise for estimating actual final timber outturn from individual stands. A change from predicted to final yield can readily occur where a crop has suffered check or other damage in establishment that delays its development and thus distorts early estimates of site potential based on growth-to-age relationships. Similarly, fertilizer application which corrects a specific deficiency may also have this impact. However, there is some evidence for very-long-rotation (>40 years) crops in temperate countries that initial prediction of yield or quality class underestimates final outturn, i.e., the crops grow better in later life than expected. Either the models derived from data of 40 or more years ago were wrong, or they are now inappropriate to present conditions, or growing conditions are improving in the sense of favoring tree growth. Across Europe, research by the European Forest Institute shows this to be happening and it is attributed to rises in atmospheric CO_2 and nitrogen input in rainfall, better planting stock, and cessation of harmful practices such as litter raking.

However, as noted earlier, the opposite may occur with teak. High initial site quality estimates do not yield the expected outturn and figures are revised downward as the crops get older. Plantation teak does suffer soil erosion in established stands, development of understories is rare, and burning of debris, especially the large dry leaves, is commonplace. Like litter raking, these practices may contribute to loss of nutrients from a site.

Relation of quality (yield) class with time of planting Closely related to the phenomenon of changing yield potential as a crop grows is the observation that date of planting is often positively related to productivity, i.e., more recent crops are more productive than older ones, regardless of inherent site fertility. This shift is measurable and can be dramatic and is well seen for *P. radiata* in Australia and New Zealand, where the more recent the planting, the more productive the stand. And in the UK, attempts to model productivity on the basis of site factors have often been forced to include planting date as a variable. Maximum mean annual growth of Sitka spruce increases by about $1\,m^3\,ha^{-1}\,year^{-1}$ for each succeeding decade up to the present. This phenomenon seems common and suggests that some process favors present growing conditions for trees over those in the past, such as the impact of genetic and silvicultural improvements – and cessation of harmful ones – and possibly the 'signature' of atmospheric changes.

Interventions to Sustain Yield

Genetic Improvement

Change in species, seed origin, use of new clones, use of genetically improved seed and, in the future, genetically modified trees all offer the prospect of better yields in later rotations.

Species change There are surprisingly few examples of wholesale species change from one rotation to the next, which suggests that in most cases foresters have been good silviculturists, drawing on trials and long experience with a species before commencing large-scale plantations. It is also worth noting that, where a successful exotic species is replaced by a native one in the second rotation for reasons of conservation or public preference, productivity may diminish.

Better seed origins, provenances, and land races The impact of these genetic improvements are well known and reported elsewhere (*see* **Tree Breeding, Practices**: Genetics and Improvement of Wood Properties). It is important to cover the range of site conditions where a species is believed to have potential owing to site – genotype interaction. The best seed origin in one location may not be the best in another. This refinement in understanding offers the prospect of further yield improvement.

Clonal plantations Some of the world's most productive tree plantations, including both eucalypts and poplars, use clonal material. Both the potential productivity and uniformity of product make this form of silviculture attractive and it is likely to expand in the future. Although clonal forestry has a narrow genetic base, careful management of clone numbers and the way they are interplanted can minimize pest and disease problems. Use of 30–40 unrelated clones per stand is usually considered to provide security against catastrophic failure in most circumstances.

Tree breeding Genetic tree improvement offers by far the greatest assurance of sustained and improved yields from plantations in the medium and long term. Improvements of 20–50% are reportedly relatively easy to achieve. A compilation of estimated percentage gains from genetic and silvicultural interventions in plantation forestry is now incorporated into the Food and Agricultural Organization's global fiber supply model.

Genetically modified trees There are presently no significant plantations of genetically modified trees, except possibly in China. The expectation is that genetic engineering may be used to develop disease resistance, modified wood properties, or cold or drought tolerance. Research in progress includes modified lignin content of eucalypts and poplars and insertion of disease-resistant genes in elms (*Ulmus* spp.).

Subject to their public acceptance, these powerful genetic tools will become increasingly cheap and hence accessible to forestry use and offer an important aid to intensification of production.

Role of Different Silvicultures

Silvicultural knowledge continues to increase through research and field trials, often focused by greater understanding of tree and stand physiology. While large yield improvements appear unlikely, several incremental gains can be expected. Examples include the following:

1. Manipulation of stocking levels to increase output of total fiber or a particular product such as high-quality sawlogs. The object will be fuller site occupancy, less mortality, and greater control of individual tree growth.
2. Matching rotation length to optimize yield – the rotation of maximum mean annual increment – offers worthwhile yield gain in many cases. Of course, other factors frequently prevail, leading to rotation lengths other than this one.
3. In some localities, such as the British Isles, prolonging the life of a stand of trees subject to windthrow will increase yield over time, since most threatened stands are felled or windblown long before maturity. Research to predict damaging storm impacts and silvicultural research which increases crop stability and stem strength assist increase in yield.
4. Use of mixed crops may help in tree stability, may possibly lower pest and disease threats, but is unlikely to offer a yield gain over growing the most productive tree species the site can support.
5. Moves to silvicultural systems that maintain forest cover at all times – continuous-cover forestry practices – such as shelterwood and selection systems are likely to be neutral to slightly negative in production terms while yielding gains in tree quality, aesthetics, and probably biodiversity value.
6. Crop rotation, as practiced in farming, appears unlikely as a feature in plantation forestry, although there are examples of tree plantations benefiting from a previous crop of nitrogen-fixing legumes such as *Acacia mearnsii*. Industry is likely to require a similar, not widely differing, species when replanting.

Traditionally, use of exotics carefully matched to site has often offered a yield gain over native species, even where suitable native species are available, owing to relative freedom from pest and diseases. This advantage cannot be expected to last indefinitely and there are already examples of increasing susceptibility of exotics to local pests and diseases.

Fertilizing

Regular and automatic application of mineral fertilizer as in much of farming practice is not presently a feature of plantation forestry, with the exception of some tropical eucalypt plantations. Most forest use of fertilizer is to correct known deficiencies, e.g., micronutrients such as boron in much of the tropics and zinc in Australia, macronutrients such as phosphorus on impoverished sites in many parts of the world, and nitrogen in some locations such as the Pacific Northwest of the USA. In most instances, fertilizer addition has only been required once in a rotation to obtain satisfactory establishment and growth.

Spectacular yields have been achieved on some sites by frequent or even annual fertilizer addition as part of intensive management that includes full weed control and optimal spacing. Examples include the British Forest Research experiment Wareham 156, the trials by Torsten Ingestad in Sweden, and the biology of forest growth experiment carried out by the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia. These trials are experimental and serve more to elucidate principles of stand physiology, applied nutrition, and maximum growth potential rather than to offer practical and economically worthwhile operational prescriptions, since wood is a low-value product. In some situations irrigation offers similarly dramatic increases in growth.

Monitoring of nutrient levels in foliar analysis or fertilizer trials has a role mainly as an aid to good overall silviculture, although increasingly foliar analysis is used in intensively managed plantations as a diagnostic growth promotion tool to inform fertilizer prescriptions. Fertilizing is likely to be the principal means of compensating for nutrient losses on those sites where plantation forestry practice does cause net nutrient export to the detriment of plant growth.

Site Preparation Establishment Practices

Ground preparation to establish the first plantation crop will normally have introduced sufficient site modification for good tree growth. Cultivation loosens soil, improves rooting, encourages drainage, limits initial weed growth, improves water percolation, may reduce frost risk and, perhaps importantly for the long-term health of the forest, brings relatively unweathered soil minerals nearer to the surface and into the main feeding zone of tree roots. Substantial new investment in site manipulation is unlikely in second and subsequent crops owing to the cost of handling stumps and the implied failure first time round. Exceptions are alleviation of soil compaction after harvesting, and measures to reduce infections and pest problems. For example, in the UK destumping and windrowing of debris on some alkaline sites helps avoid fomes infection (*Heterobasidion annosum*).

Weed control strategies may change from one rotation to the next, owing to differing weed spectrum and whether weeds are more or less competitive to planted trees. The issue is crucial to sustainability since all the main examples of yield decline problems cited earlier reflect worsening weed environments, especially worsening competition from monocotyledons such as grasses and bamboos.

Changes between rotations in treatment of felling debris and organic matter may occur, such as cessation of burning, use of windrowing, or removal from site in whole-tree harvesting. It is clear that the felling, harvesting, and reestablishment phase is crucial to sustainable practice and needs to be viewed as a whole to minimize impacts from compaction along extraction routes, from loss of organic matter, and from soil erosion.

Organic Matter Conservation

Treatment of organic matter both over the rotation and during felling and replanting is as critical to sustainability as coping with the weed environment. While avoidance of whole-tree harvesting is probably desirable on nutrition grounds, both prevention of systematic litter gathering during the rotation and careful handling of accumulated organic matter at harvesting are essential to minimize disturbance and help aeration of soil and accelerate decomposition. Many authors attribute poor tree growth of the past and evidence of increasing yields in many plantations today to better conservation and handling of organic matter.

Holistic Management

Where all the above silvicultural features are brought together, a rising trend in productivity can be expected. If any one is neglected, it is likely that the whole will suffer disproportionally. For example, operations should not exclusively minimize harvesting costs, but rather those of harvesting, reestablishment and initial weeding should be taken as holistic activity, and without impairing tree vigor.

Holistic management also embraces active monitoring of pest and disease levels, and researching pest and disease biology and impacts will aid appropriate responses such as altering practices, e.g., delayed replanting to allow weevil numbers to fall. Careful reuse of extraction routes to minimize compaction and erosion is a further example.

Conclusions

Three main conclusions may be drawn from this review of yield assessments made over long periods, and often more than one rotation, and the summary of interventions to sustain yields.

1. Measurements of yield in successive rotations of trees suggest that there is no significant or widespread evidence that plantation forestry is unsustainable in the narrow sense. Where yield decline has been reported, poor silvicultural practices and operations appear to be largely responsible.
2. Evidence in several countries suggests that current rates of tree growth, including in forest plantations, exceed those of 50 or 100 years ago owing to changes in the environment, especially atmospheric composition, and improvements in silviculture.
3. There are several interventions in plantation silviculture which point to increasing productivity in the future, providing management is holistic and good standards are maintained. Genetic improvement in particular offers the prospect of substantial and long-term gains in yield over several rotations.

See also: **Afforestation**: Species Choice; Stand Establishment, Treatment and Promotion - European Experience. **Inventory**: Stand Inventories. **Plantation Silviculture**: Forest Plantations; Rotations; Stand Density and Stocking in Plantations; Tending. **Resource Assessment**: Forest Resources. **Silviculture**: Natural Stand Regeneration. **Sustainable Forest Management**: Certification; Overview. **Tree Breeding, Practices**: Breeding for Disease and Insect Resistance; Genetics and Improvement of Wood Properties. **Tree Breeding, Principles**: Conifer Breeding Principles and Processes.

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Short Rotation Forestry for Biomass Production

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Introduction

Some hardwood species have very rapid juvenile growth and also coppice readily. They are often natural pioneers. High yields can be sustained over many coppice rotations as short as 3–15 years. These properties can be exploited to produce large quantities of woody biomass, which can be used for pulp or to produce energy.