Cockatoo sands soil survey: assessment of the potential irrigation areas, Kununurra area, East Kimberley

Henry Smolinski
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Henry Smolinski, Kus Kuswardiyanto, Justin Laycock

August 2010
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Note: Data from 245 individual field sites surveyed for this report and chemical analysis from seven sites are available from DAFWA’s soil database and accessible on the Department’s website in pdf form.
Summary

This report identifies areas of sand and loamy soils in the Kununurra area that would be suitable for horticultural development.

It is based on a soil survey commissioned by the Department of Agriculture and Food, Western Australia and funded through the State Government’s Royalties for Region Scheme. Field work was conducted during July and August 2009. Areas selected for assessment were initially identified from existing broadscale land system mapping conducted by DAFWA’s Rangeland Survey staff and previous studies undertaken by CSIRO and DAFWA.

The Cockatoo sands have the best potential for horticulture. These soils are characteristically deep red sands and sandy earths that are well drained and capable of cultivation early in the dry season. Pago sands are deep brown sands that can also be developed for horticulture, although their utilisation is limited by seasonal waterlogging.

Soil analysis indicates that there are no chemical limitations to the development of Cockatoo or Pago sands. Overall, the soil chemical and physical characteristics are comparable or better than existing horticultural soils developed within the Pilbara and south west of WA. In considering the most suitable soils, the main characteristics are drainage, risk of soil erosion under high rainfall, and excessive inputs of nitrogen through fertiliser use.

Following the field survey which included examination of 245 individual sites, approximately 8000 hectares of Cockatoo sands were identified close to the existing Stage 1 or proposed Stage 2 irrigation areas. Significant parcels of land (1000-2000 ha) border the Victoria Highway, south-east of Kununurra and north of Carlton Hill Road, west of Stage 1.

A uniform area of more than 37,000 ha of Cockatoo sands (loamy phase) is centred about 50 km north of the Ord River off Ningbing Road.

In total, about 52,000 ha of suitable land consisting of Cockatoo and Pago soils were identified (summarised in Table 1), with significant areas consisting of approximately:

- 2000 ha of Cockatoo sands and 1500 ha of Pago sands along the Victoria Highway south-east of Kununurra
- 3000 ha of Cockatoo sands and 1000 ha of Pago sands in the Carlton Hill area just north-west of the current irrigation area and west of Stage 2
- 37,000 ha of uniform Cockatoo sand (loamy phase) in the Ningbing North area, 60 km north of the current irrigation area.

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Introduction

The objective of the soil-landform assessment was to identify and characterise the unalienated sandy and loamy soils within the Kununurra area, referred to locally as Cockatoo sands, and determine their capability for horticulture.

Horticultural development on the Ord first occurred after 1962 with the release of five farms on the Ivanhoe Plain and was based initially on flood irrigation of the Cununurra cracking clays which are the dominant soils on the floodplain.

Cununurra clay was favoured for broadscale flood irrigated horticulture due to its high water-holding capacity, shrink-swell properties and occurrence on level plains adjacent to water. Cununurra clay is a very dark grey-brown cracking clay, known locally as black soil (Burvill 1991). It is formed from red-brown alluvium consisting of an admixture of sands, silts and clays, which is usually unaltered below 120-160 cm.

Development of sands and loams within the Kununurra area was limited to alluvial soils bordering the Cununurra clays. The deep colluvial sands and sandy earths derived from the sandstone occurring on the periphery of the floodplain were generally not selected for development - low water-holding capacity and greater cost of irrigation limited their development. Perennial crops grown on sand and medium-textured loams were also prone to termite attack.

The development of micro-irrigation systems and non-residual insecticides to control termites now allows a viable management system to develop the sands and loamy soils within the Kununurra area and opens up opportunities for diversification.

Development of perennial crops would suit better drained soils i.e. higher production rates for sandalwood can be achieved on deep coarse-textured soils under drip irrigation. Tree crops could also access shallow groundwater thus reducing the need for irrigation early in the dry season.

The ability to cultivating sands and loams shortly after the wet season would provide the opportunity to establish several annual fruit or vegetable crops during the dry season instead of the one crop that can be achieved on the cracking clays.

Previous studies

Existing soil-landform mapping from the Kununurra region has been consolidated by Tille (2010, in prep). This draws mainly from 1:250,000 land system mapping conducted by DAFWA’s rangelands and soil survey staff. Map units represent land systems or subunits of subsystems that consist of recognisable associations of vegetation, landscape and soil type.

The methodology of land system mapping and broad land systems was initially developed by Christian and Stewart (1953), Speck et al. (1960) and Stewart et al. (1970).

Within the Kununurra area, Cockatoo land system comprises the highest proportion of level to very gently undulating sandplain and pediments that consist of deep sands and loams. Cockatoo land system covers approximately 150,000 ha, with the dominant areas north of Kununurra to the Joseph Bonaparte Gulf and shown in Figure 1, and shown in larger format in map sheets 1-3.

The Cockatoo land system and Cockatoo family of soils were described by Stewart et al. (1970) although reference to Cockatoo sands appears in earlier surveys (see Burvill 1991).
Brief soil investigations by Van Cuylenberg (unpublished, 1977) identified the Pago, Cajuput, Elliot and Cullen families of sandy and loamy soils as subdivisions of the Cockatoo family. In particular, Pago and Cajuput sands were recognised as being more leached and prone to subsoil waterlogging. Pago sands are described as brown sands or clayey sands while Cajuput sands were paler yellow-brown sands.

Subsequent more detailed soil mapping carried out by Dixon and Petheram (1979) and Dixon and Holman (1980) provided a comprehensive assessment of the sandy soil types and their capability for sugar cane and groundnut production. These studies also identified soil drainage and erosion hazard as major factors that need to be addressed in regard to sustainable horticultural development.

It can be concluded that the well drained Cockatoo sands have the best potential for horticultural development, while soils belonging to the Pago and Cajuput families have a fair capability for specific development provided stringent soil conservation management principles are followed.
Survey area
On the basis of existing soil assessments, areas of Cockatoo land system were the main focus for this study.

Prior to assessment, meetings were conducted with representatives of the Ord Irrigation Development Authority and local stakeholders including horticulturalists and regional indigenous representatives from Yawoorroong Miriuwung Gajerrong Yirrgeb Noong Dawang Aboriginal Corporation (MG Corporation).

To take advantage of existing irrigation infrastructure and facilitate immediate expansion of the horticulture industry, initial surveys were mainly directed to areas adjacent to Stage 1 and the periphery of Ivanhoe and Packsaddle Plains.

A cursory assessment was also undertaken within the Mantinea area in view of potential future expansion.

Areas selected for assessment included:

- Sugar Mill South - areas south-west from the Sugar Mill off Mulligan’s Lagoon Road.
- Victoria Hwy - broad plains and low rises bordering the Victoria Highway, south-east of Kununurra. Dixon and Petheram (1979) identified large tracts of Cockatoo and Pago sands in this area which is relatively close to Kununurra and the Ord River.
- Carlton Hill - Dixon and Petheram identified a complex of Cockatoo, Pago and Cajuput sands north and south of Carlton Hill Road.
- Ningbing North – large tracts of Cockatoo land system north of Ningbing Road to Joseph Bonaparte Gulf.
- Lookout Springs - area of pediments and sandplain adjacent to Lookout Springs extending west to Ningbing Road.
- Stage 2 South – several areas of Cokatoo and Pago sands adjacent to the Northern Territory border.
- Ivanhoe West - minor areas of Pago sands occurring on footslopes west of the Ivanhoe Plain.
- Packsaddle - minor areas of Cockatoo and Pago sands.

Figure 1 shows the existing soil surveys within the Kununurra area, potential development areas and other local features.
Figure 1 Soil survey areas in the East Kimberley discussed in this report
Methodology

Prior to the 2009 soil survey a desktop study utilised existing soil-landscape and geology mapping draped over current digital aerial photography as a preliminary soil mapping base. Sun-shaded digital elevation model (DEM) and gamma radiometrics were also incorporated to identify geology, landscape patterns and potential areas of sand.

Detailed mapping produced by Dixon and Petheram (1979) was useful in defining soil associations with corresponding vegetation patterns soil surface and landscape features. This provided a comparative assessment of vegetation with soil unit areas that allowed the extrapolation and identification of various soil units outside the current surveyed areas.

The units identified in previous surveys were checked to familiarise the surveyors with various soil types. Once the soil-landscape and vegetation patterns were verified against the various GIS themes, field survey was used to confirm the extent of sand and loamy soils, particularly the Cockatoo sands.

Field survey was conducted between 30 July and 13 August 2009 by Henry Smolinski, Kus Kuswardiyanto and Justin Laycock.

Field traverses were restricted to existing roads and tracks to avoid the risk of punctures and opening up new tracks to the public that could result in soil disturbance.

Most soil profiles were identified from shallow (40 cm) shovel pits and auger borings to 2 m, restrictive rock or hardpan, if this was encountered first.

The terminology of McDonald et al. (1998) was adopted in describing the sites. Data routinely recorded on field sheets included:

- vegetation structure and dominant species
- landform features
- soil colour — using the Munsell Color Chart (Munsell Color Company 1975)
- soil texture—described by hand texturing
- soil structure
- presence of gravel and segregations
- soil pH using field kit (Raupach and Tucker 1959)
- soil salinity using a pocket electrical conductivity (EC) meter
- depth to groundwater or saturated soil horizon.

The observation site locations were recorded using a standard GPS unit (Garmin GPS76) set to GDA94 datum.

On return to the office, information on the field sheets was inputted into DAFWA’s soils database under the COCS project.

Soil profiles were classified using the Soil groups of Schoknecht (2002) and the Australian Soil Classification (Isbell 2002).

Soil mapping and area calculations were carried out with Geomedia GIS software.
The soil map units specifically identify the extent of Cockatoo and Pago family soils, which are considered to have a high to fair capability for horticulture development. Unlike standard soil-landform mapping techniques where all soil-landform units are identified within the survey area, this process allows for rapid assessment. This form of survey is possible as it builds on existing low to medium scale mapping and is aided by detailed aerial photography and radiometrics.

The purity of the map units is based on 245 field observation sites (see website), which equates to an observation density of about one site per 200 hectares and suitable for a mapping scale of 1:75,000 (McKenzie 2008).

On completion of soil mapping, additional field work was carried out in March 2010 to assess soil drainage within the soil map units and particularly within areas of Pago sands that are prone to seasonal waterlogging.
Soils

Soils have been described by Stewart et al. (1970) and Dixon and Petheram (1979). Soils suitable for horticulture include the Cockatoo sands and Pago sands. Figure 1 identifies areas of Cockatoo and Pago sands within the Kununurra area and map sheets 1-3 provide a more detailed outline of the soils over current digital aerial photography and satellite imagery.

The Cockatoo sands and associated soils occur within the Cockatoo land system. A brief description of the Cockatoo land system is provided below, adapted from Speck et al. (1960) and Stewart et al. (1970).

This unit is very gently undulating to gently undulating sandplain that carries tall woodland. The soils are associated with unconsolidated sands and reworked alluvium derived from ferruginous quartz sandstones and siltstones of Proterozoic age.

Surrounding the township of Kununurra, Cockatoo land system includes sandstone hills, pediments and sandplains with well defined dendritic drainage systems near sandstone outcrops and poorly drained flats and floodplains. North of Kununurra towards Joseph Bonaparte Gulf, the land system is associated with coastal erosional plains with widely spaced ephemeral streams developed from sheet flow that grade to swamps and broad erosional valleys adjacent to tidal flats.

Cockatoo sands

Red sands, Red sandy earths and Red loamy earths (see Soil groups, Schoknecht 2002) are the most common soils grouped under the Cockatoo soils family with sandy earths being most typical. These are defined as Red Kandosols (sandy earths and loamy earths) or Red-Orthic Tenosols (deep sands) in the Australian Soil Classification (Isbell 2002).

Topsoils usually have a loose to firm surface (0-2 cm) of dark brown or dark reddish brown sand to clayey sand overlying a firm brown, yellowish red or red sand to clayey sand. The loose surface layer has probably formed through bioturbation and seasonal sheet flow.

Yellowish red to dark red clayey sand to light sandy clay loam is encountered at 40 cm and may extend below 200 cm. The texture of this horizon determines if the soil is classified as sand, sandy earth or loamy earth, where:

- Sands have loamy sand to clayey sand subsoils
- Sandy earths have loamy sand grading to sandy loam or light sandy clay loam subsoils
- Loamy earths have sandy loam to sandy clay loam lower topsoil and subsoil horizons.

Soil particle size analysis indicates that all soil variants display an increase in clay content with depth. This increase is normally diffuse or gradual. Loamy earths occurring within the Ningbing North area are an exception, i.e. loamy earths with light sandy clay loam subsoils occurring at 40 cm may exhibit clear horizon boundaries and compact layers. Lower subsoil horizons may also exhibit a few yellow-brown mottles below 150 cm which may indicate a period of soil saturation. Nevertheless, soil investigations in March 2010, immediately after the wet season, did not encounter perched watertables or saturated soil horizons within the Cockatoo sands.

Cockatoo sands commonly have a neutral soil reaction trend. Topsoil horizons usually have a pH range of 6.0-6.5, measured in water at a ratio of 1:5 (pHw), while subsoils vary between pHw 6.0 and 7.0.
Soluble salt content is negligible within the soil profile.

Soil structure is commonly massive with a sandy to earthy fabric within the upper 40 cm of the soil profile. Subsoils grade from sandy to earthy fabric. Moderately moist subsoils that have light sandy clay loam or sandy clay loam texture may exhibit a crumb or weak granular structure. Numerous pores are evident throughout the soil profile.

Soil consistence is very weak to weak in the dry state for textures from loamy sand to clayey sand. Sandy loam or clay loam horizons have a weak to firm consistence when dry.

Ferruginous gravel or sandstone layers can be encountered within the subsoil below 150 cm.

Sandstone layers are weakly cemented to indurated, however perched watertables were not encountered within the Cockatoo sands at the time of survey.

Figure 2 represents a typical Red sandy earth (Cockatoo sands profile). Note the earthy (porous) fabric and underlying sandstone at 100 cm.

Figure 2 Typical Cockatoo sands - Red sandy earth on sandstone
Pago sands

Pago sands were initially described by Speck et al. (1960) and Stewart et al. (1970) as deep yellow sands ranging in texture from sand to loamy sand and appearing to have similar morphology as sandy variants that belong to the Cockatoo sands, apart from the yellow-brown subsoil (see Figure 3). These soils are classified as Yellow or brown deep sands (Schoknecht 2002) and Yellow-Orthic or Brown-Orthic Tenosols (Isbell 2002).

Figure 3 Typical example of yellow-brown Pago sands

Speck et al. (1960) described Pago sands as deep, coarse textured and well drained and that they occurred in association with Cockatoo sands and poorly drained deep light grey sands (Speck et al. 1960 p. 35).

Dixon and Petheram (1979) described Pago sands as soils with yellow–brown subsoil with hues browner than 5YR (Munsell Color Company 1975), which implies that strong brown, reddish yellow and brownish yellow sands are grouped under the Pago sands.
Dixon and Petheram recognised that some Pago soils were prone to subsoil waterlogging, contrary to what was suggested by Speck et al. (1960). Furthermore, Dixon and Petheram, (1979) assigned Cajuput soil series to the poorly drained light grey or pale yellow sands in recognition of the *Melaleuca* species that were commonly associated with this soil.

Speck et al. (1960) assessed soil profile drainage based on auger holes to 100-120 cm. During the recent survey, saturated soil horizons were commonly encountered below 140-200 cm, within areas of Pago sands.

In following Dixon and Petheram’s description, Pago sands usually have greyish brown sand to loamy sand topsoil horizons overlying light yellowish brown to brownish yellow sand. Brownish yellow, reddish yellow or strong brown loamy sand or clayey sand occurs at about 40 cm and may extend below 200 cm. Few to common yellow-brown or red mottles may be evident below 140 cm.

Standing or perched watertable may be encountered below 140 cm, otherwise a saturated layer is commonly encountered within 200 cm.

Not all Pago sands had a saturated soil horizon within 200 cm. However, soils that did, all carried dense stands or isolated clumps of *Melaleuca viridiflora* (see p. 88, McDonald et al. 1998). It should be noted that east of Kununurra (see map sheet 3, Victoria Hwy) perched watertable levels were static between late July and late August which suggests impervious substrates may be encountered in this area. Wheel ruts were more evident within areas of Pago sands that indicate longer periods of soil profile saturation.

Pago sands usually have loose topsoil and the profile is structureless within the upper 20-40 cm. Soil consistence is loose or very weak in the dry state.

Subsoils are structureless, single-grained or massive with a very weak or weak consistence.

Soil reaction trend is acid to neutral. Topsoil pH is commonly 6.0 while subsoils are 6.0-6.5.

Soluble salt is negligible throughout the soil profile (<5 mS/m).

**Other soils**

Other variants occurring in association with Pago sands include the Cullen and Elliot family soils (Dixon and Petheram 1979), and unnamed loamy red duplex soils.

Cullen soils have dark greyish brown topsoils over light yellowish brown or brown loamy sand to clayey sand lower topsoils. Yellowish brown to strong brown clayey sand to sandy loam occurs at about 40 cm. Brownish yellow light sandy clay loam or sandy clay loam may be encountered at 110-140 cm. Lower subsoils usually exhibit red-brown mottles and ferruginous segregations. Cullen soils are not extensive and usually found bordering drainage lines, which suggests an alluvial origin.

Soil profiles appear to be moderately well drained with saturated layers not encountered within 150 cm.

Elliot family soils are similar to Cullen and could be considered finer-textured variants. Topsoils are dark brown sandy loam overlying brown or dark yellowish brown sandy loam to light sandy clay loam. Yellowish brown mottled sandy clay loam or sandy clay may be encountered within 150 cm.
Shallow to moderately deep, loamy red duplex soils were also encountered along drainage lines and alluvial flats. Topsoils are dark red-brown loams overlying red-brown sandy clay to light medium clay.

The Cullen, Elliot and loamy red duplex soils generally exhibit a massive structure and as indicated by the vegetation, internal drainage is likely to be moderately well drained to imperfectly drained. Seasonal inundation and subsoil waterlogging would be apparent in areas of red duplex and Elliot family soils.
Vegetation associations

As discussed by Dixon and Petheram (1979), the presence or absence of individual plants has no value in the assessment of soil or land type, but the occurrence of a combination or association of plant species, plant structure and density provides a better indication of soil type and soil drainage.

Results from this survey would generally agree with the findings of Dixon and Petheram with the exception that *Melaleuca viridiflora* (broadleaf paperbark) was a good indicator of saturated soil horizons occurring within a depth of 200cm. The occurrence of *M. viridiflora* (i.e. one tree in 1000 m$^2$) distinguished the Pago soils from the better drained Cockatoo soils. *M. viridiflora* was also associated with a change in species composition, structure and density which is difficult to quantify within a vegetation community frequently modified by fire.

General vegetation associations encountered in the survey area are as follows:

**Cockatoo sands** support *Eucalyptus tetrodonta* (Darwin stringybark), *E. miniata* (woollybutt), *Erythrophleum chlorostachys* (ironwood), *Acacia tumida* (pindan wattle), *A. platycarpa* (pindan wattle), *Grevillea agrifolia* (blue grevillea), *G. pteridifolia* (silky grevillea) and *Owenia vernicosa* (emu apple).

The occurrence of open woodland or woodland with *E. tetrodonta* as the dominant emergent species indicated Cockatoo sands. *E. tetrodonta* formed pure stands or an association with *E. miniata*. *E. miniata* rarely occurred as the dominant species or in pure stands.

The common occurrence of *Brachychiton tuberculatus* (large leaf kurrajong) in the understorey of *E. tetrodonta* woodland indicated loam or clay loam subsoils.

**Pago sands** carry a similar vegetation structure and species composition to Cockatoo sands, however species composition is more varied and woodlands tend to be more open.

*E. tetrodonta* is present but not always the dominant emergent species. It often forms an association with *Corymbia ferruginea* while *Eucalyptus confertiflora* (roughleaf cabbage gum), *E. miniata* (woollybutt) and *E. chlorostachys* (ironwood) may also be present.

Soils that are more prone to waterlogging (i.e. watertables between 100 and 150 cm) rarely carry *E. tetrodonta* or *E. miniata*. Common emergent species are *C. ferruginea*, *E. confertiflora*, *Corymbia foelscheana* and *Eucalyptus polycarpa* (long-fruitied bloodwood). *M. viridiflora* is common with the understorey species, *Platyzoma microphyllum* (braid fern) and *Blumea* species.

**Texture contrast soils**, seen as duplex soils and soils having clay subsoils within 150 cm, are prone to waterlogging. These soils usually carried very open to open woodland with low to medium height emergents.

Common species include *Eucalyptus bigalerita* (northern salmon gum), *E. obconica*, *E. pruinosa* (silver box), *E. grandifolia* (large leaf cabbage gum), *E. confertiflora*, *Melaleuca minutifolia* (tea tree), *M. viridiflora* (broadleaf paperbark), *Hakea lorea* and *Grevillea striata* (beefwood).
Soil analysis

Soil analysis was carried out on seven representative soil samples from Cockatoo sands (sites 121, 133, 201), Pago sands (sites 204, 216) and medium-textured Cullen family soil (site 234), all obtained from uncleared land. Analysis was also conducted on a Cockatoo sand that is currently used for cucurbit production.

Under native vegetation, the soil nutrient status is extremely low. Topsoil horizons contain negligible nitrogen and phosphorus. Potassium status is low to high which may reflect the mica content within the soil parent material (i.e. ferruginous sandstones, siltstone and shale).

Organic carbon is less than 0.5 per cent within the topsoil while subsoils contain less than 0.2 per cent, which indicates a rapid biocycling and poor topsoil accumulation of carbon under dry tropical climatic conditions.

The Cockatoo and Pago sands generally have loamy sand to clayey sand topsoil textures containing a silt plus clay content of 8-10 per cent while subsoil horizons contain 8-20 per cent clay. The fine sand fraction is commonly 10-20 per cent.

The well drained to rapidly drained characteristic of the soil profile is consistent with low clay content and also supported by very low salt content.

Exchangeable cations are dominated by calcium and magnesium, although magnesium may be dominant within clay loam subsoils. All soils exhibited very low sodium content.

Soil pH analysis confirmed Inoculo field tests (Raupach and Tucker 1959) that indicate soil pHw is commonly in the range of 6.0-6.5 throughout the soil profile with most values near 6.5.

Soil phosphorus retention index values (PRI) can be classified as medium (see p. 236, Moore 1998). PRI values increase with depth, in line with increasing clay and iron content.

Topsoil and lower topsoil horizons are near phosphorus saturation under 14 years of annual horticulture (see sample 211a,b) however, low subsoil PRI values (see sample 211c) indicate negligible phosphorus movement into subsoil horizons.
Soil limitations

Analysis indicates that there are no chemical limitations to the development of Cockatoo or Pago sands. Overall, the soil chemical and physical characteristics are comparable or better than existing horticultural soils developed within the Pilbara and South West of the State.

Even so, the sands, sandy earths and loamy earths show evidence of inherent subsoil compaction and the loamy earths readily slake. Subsoil compaction is likely to be exacerbated by frequent cultivation when the soils are moist. Subsoil compaction and surface slacking can be minimised through periodic deep-ripping, controlled traffic, and fallow or maintenance of vegetative cover in the wet season. Without appropriate management soil compaction would contribute to soil erosion risk.

The main characteristics that need to be considered are soil drainage, the risk of erosion under a high rainfall environment and excessive inputs of nitrogen through fertiliser use.

Soil drainage

Soil drainage is not a major limitation to the development of the Cockatoo sands. Soil profiles are well drained to rapidly drained within the upper 150-200 cm. Exceptions would be areas that contain shallow sandstone, but from our limited assessment of existing areas of Cockatoo sands under horticulture, sandstone substrates can be highly porous and not impede infiltration.

For Pago sands, a leached profile, association with lower landscape positions and persistence in some areas of a shallow (<200 cm) groundwater table suggest that horticultural development may induce a rise in the groundwater. However, this scenario depends on the nature of the substrate, its hydraulic conductivity and depth to the regional groundwater table e.g. local watertables under established horticulture blocks can range from 60 to 150 cm over short distances where the underlying substrate is sandstone with a sand to loam matrix.

Soil investigations in March 2010 confirmed the seasonal dynamics of the groundwater under Pago sands were highly variable, i.e. standing watertables were absent, remained static or fluctuated seasonally by 100-150 cm. Further monitoring is required to determine the seasonal dynamics of the groundwater under Pago sands.

Soil erosion

Soil erosion is a major limitation that needs to be addressed in the development of both Cockatoo and Pago sands. Severe sheet and gully erosion was evident along tracks and fencelines, particularly in areas with long slopes and grades greater than 1 per cent.

The development of gullies was more common and severe on Pago sands that have loose or very weakly coherent topsoils. Under major rainfall events the soil profile can become saturated and reach its liquid limit. The formation of gullies more than 100 cm deep was apparent, particularly in areas that have sandstone or clay substrates within 200 cm.

It is unlikely that the soil conservation banks would be successful in controlling water erosion under high rainfall events. The incorporation of vegetation belts or reserving Pago soils for perennial horticulture would be more appropriate.
Nutrient leaching
The risk of eutrophication resulting from the application of nitrogen fertiliser can be high on rapidly drained sandy soils and under a climate of high evapo-transpiration. This risk can be minimised with soil moisture monitoring probes linked to irrigation and fertigation management systems.

Higher risk of nutrient leaching would be associated with Pago sands having watertables at 100-200 cm or areas that have impervious substrates. Deep-rooted annual crops or tree crops would be more appropriate in these areas.
Map units

The extent of Cockatoo and Pago sands within the eight survey areas is shown in map sheets 1-3 while Table 1 list the areas of Cockatoo and Pago sands within each area.

As stated in the methodology, the map units are appropriate at a scale of 1:75,000, which allows for the identification of uniform soil areas of about 20 ha. Therefore, minor pockets of sandstone, wet depressions and drainage lines may be included within map units.

Where practicable, the map units are defined as homogeneous, i.e. areas of Cockatoo sands generally represent soils with profiles greater than 200 cm, although areas of shallow sandstone, sandstone outcrop or laterite gravelly soils may be included within these units as the surface features and colours often appear similar on aerial photography.

Areas of shallow gravelly Cockatoo sands were amalgamated with Pago sands units as drainage status and soil erosion risk is a limitation to both soil groups.

Areas of Pago sands may include areas of Cajuput sand and similar poorly drained soils as it was not possible to delineate uniform areas within a landform containing a network of minor flowlines and depressions.

Table 1 Areas of Cockatoo and Pago sands

<table>
<thead>
<tr>
<th>Survey area</th>
<th>Cockatoo sands (ha)</th>
<th>Pago sands (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carlton Hill</td>
<td>3,373</td>
<td>1,028</td>
</tr>
<tr>
<td>Ivanhoe West</td>
<td>0</td>
<td>433</td>
</tr>
<tr>
<td>Lookout Springs</td>
<td>1,896</td>
<td>2,882</td>
</tr>
<tr>
<td>Ningbing North</td>
<td>37,198</td>
<td>82</td>
</tr>
<tr>
<td>Packsaddle</td>
<td>41</td>
<td>37</td>
</tr>
<tr>
<td>Stage 2 South</td>
<td>326</td>
<td>759</td>
</tr>
<tr>
<td>Sugar Mill South</td>
<td>149</td>
<td>512</td>
</tr>
<tr>
<td>Victoria Hwy</td>
<td>2433</td>
<td>2089</td>
</tr>
<tr>
<td><strong>Total area</strong></td>
<td><strong>45,416</strong></td>
<td><strong>7,822</strong></td>
</tr>
</tbody>
</table>
Areas of horticultural potential

The results from this soil survey indicate that approximately 53,000 ha of sands and sandy earths have potential for horticultural development within the Kununurra area. Most of this is situated off Ningbing Road, 50 km from current irrigation infrastructure or surface water supplies.

Areas of Cockatoo and Pago sands adjoining current irrigation areas comprise about 1000 ha. Incorporation of these areas into the irrigation scheme would involve the establishment of at least 4 km of irrigation pipe or channel.

Significant areas of Cockatoo and Pago sands (more than 3000 ha) occur off Carlton Hill Road, Victoria Highway and near Lookout Springs. Development within these areas would also require the establishment of 7 to 15 km of irrigation pipe or channel.

Within the areas surveyed, Cockatoo sands have the best potential for horticulture provided that clearing and soil management plans minimise the risk of soil erosion.

Development of the Pago sands would require a higher level of management as soil erosion is likely to be exacerbated by seasonal perched watertables and associated restrictions to vehicle access.

To verify the suitability of the areas, it would be necessary to assess the drainage characteristics of soils, particularly the Pago sands during the wet season. Provided the upper 100 cm of the soil profile is free draining early in the dry season, it may be possible to use Pago sands under intensive horticulture. There is also opportunity to develop low maintenance deep-rooted crops or tree crops such as sandalwood within these areas.

Deep-rooted tree crops could take advantage of the perched watertables and reduce the requirement for irrigation and associated infrastructure development.
References and bibliography


Dixon JC, Petheram RJ (1979) Soil potential for groundnut production at Kununurra, Western Australia. Technical Bulletin No. 50. Western Australian Department of Agriculture.


