SOIL CONSERVATION IN UPLAND JAVA, INDONESIA: PAST FAILURES, RECENT FINDINGS AND FUTURE PROSPECTS

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Abstract
Despite widespread bench-terracing programmes, the Indonesian island of Java continues to experience severe soil loss and sediment problems. The Cikumutuk Hydrology and Erosion Research Project (1994-2001) studied the underlying biophysical and socio-economic causes of erosion in a small agricultural upland catchment in West Java. Most stream sediment was generated on the cropped bench terraces, but soil loss could be reduced up to six-fold by a combination of mulching, denser vegetation, and simple measures in the terrace drain. Sediment storage en route to the stream was small and ensures that soil loss reduction will rapidly lead to stream sediment load reduction. The observed soil fertility decline is unlikely to be reversed by soil conservation alone, but could be mitigated by more efficient use of harvest residues and rotation with fast-growing nitrogen-fixing tree plantations. The low revenues from rain-fed cropping and insecurity of land tenure are central to the land degradation problem, but farmer innovators in the area are developing improved forms of land husbandry that appear viable on a larger scale if land rights can be secured.

Additional Keywords: Indonesia, soil loss, sediment, soil conservation, bench terrace

Introduction
Accelerated erosion continues to threaten agricultural production in the uplands of the Indonesian island of Java. Stream sediment also smothers freshwater and coastal-marine ecosystems, reduces the efficiency and lifetime of irrigation works and dams, and affects the navigability of lowland rivers. Numerous costly upland rehabilitation projects have resulted in widespread bench-terracing but by and large failed to decrease river sediment loads or enhance the well-being of upland farmers. This has given rise to a debate about the actual sources of river sediment and the time it takes for reductions in 'on-site' erosion to result in decreased sediment fluxes downstream (Purwanto, 1999).

The Cikumutuk Hydrology and Erosion Research Project (CHERP) was initiated in 1994 as a joint effort by the Vrije Universiteit Amsterdam and the Indonesian Ministry of Forestry to study the socio-economic and biophysical causes of the lack of impact of soil conservation programmes. The research was concentrated within a small catchment that may be considered representative of much of West Java's agricultural volcanic uplands. The project addressed the following questions:
- What are the main sources of sediment within the catchment?
- Assuming that much sediment is still generated on the rain-fed bench terraced hillsides, where and how on the terrace is it generated, how efficient and rapid is its delivery to the stream, and how can soil loss be reduced most effectively?
- What are the socio-economic impediments to uptake of better land husbandry practices by local farmers?
- What impact are changes in land husbandry likely to have on sediment, water, nutrient and carbon budgets, and, indirectly, on crop productivity?

Because of the breadth of the field research undertaken, the methods and results are only outlined broadly in this paper. The reader is referred to the cited references for more detailed descriptions of the study area, research methods, results and conclusions (also available via *http://www.geo.vu.nl/~trendy/CHERP.html*).

Materials and Methods
Study area
Research was conducted in the 125 ha upper catchment of the Cikumutuk River near the town of Malangbong, about 40 km east of Bandung, West Java, at an altitude of 580—610 m above sea level (7°03´S, 108°04´W; Figure 1). Slopes are generally steep (mean ~15º). The geology is composed of Pliocene to Pleistocene volcanic breccias covered by 1—2 m of Quaternary andesitic volcanic ashes. The ashes have weathered to a kaolinitic oxisol dominated by silt and clay that consists of several decimetres of highly permeable, well-aggregated soil on top of less permeable, massive subsoil. The area experiences a humid tropical climate with a mean annual rainfall of

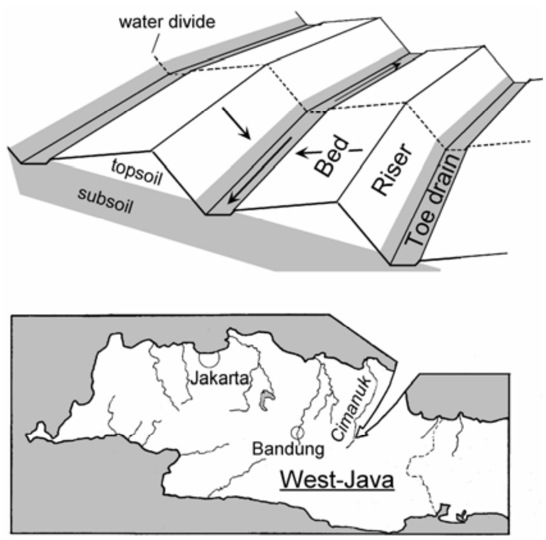

Figure 1. Location of the study area and general design of the back-sloping bench terraces.

~2650 mm (1994—2001), of which more than two-third falls during the rainy season (November to May). In 1998, approximately 75 households or 320 people relied on agriculture within the catchment for a significant part of their income. The mean holding included 1.3 ha of rain-fed land, but the distribution of farm sizes was skewed with a median holding of only ~0.3 ha (Purwanto, 1999).

Bench terraces were constructed on most hillsides as part of a major soil conservation programme in the 1980s. A typical terrace unit consists of a riser, a compacted central drain and a bed that slopes backwards towards the central drain (Figure 1). The terrace risers typically have slopes of 35—50º and a projected width of 0.5—1.3 m, whereas the terrace beds have slopes of 0—12º and a width of 0.8 m or more (also depending on the original slope). The central drains are typically 0.3—0.4 m wide and have a slight gradient towards the end of the terrace (normally 1—3º), where runoff and sediment from the terraces drain into a small gully or onto a downslope trail. Terraces often drain towards two sides with a central water divide at 15—40 m from either end (Figure 1). Crops planted on the rain-fed terrace bed usually include inter-cropped cassava and maize, sometimes with a third crop (upland rice, groundnuts or another legume). The crops are sown or planted a few weeks after the first frequent rains in October-November, and harvested in February-March, except cassava which is usually left to grow until the end of the dry season (August-October).

Methodology

The sources and pathways of stream sediment and the effectiveness of different soil conservation measures were studied through a combination of field research and modelling. The catchment sediment budget was established by combining measurements of runoff and sediment yields associated with different land uses (a settlement area, rain-fed cropland, a series of paddy rice fields and a plantation forest) and from the entire 125 ha catchment with surveys of stream bank erosion and erosion and deposition within the hillslope drainages. Measurements on cropped bench terraces (with and without soil conservation measures) were made for six years and over a range of scales; from sections of bench terraces (1—6 m^2; 47 plot-seasons), via six terrace units (50—230 m^2; 16 plot-seasons) and two groups of terraces (0.1—0.3 ha, 3 plot-seasons) to two hillslope sub-catchments (4 ha, 4 plot-seasons). Combined with detailed process research (Van Dijk *et al.*, 2003ab), these measurements led to an improved understanding of erosion and sediment transport on bench terraces. A model of runoff and sediment generation on bench terrace units (TEST: Terrace Erosion and Sediment Transport) was developed and used to simulate field measurements made on (sections of) bench terraces and at the hillslope scale. Field measurements and modelling results are described in Purwanto (1999), Van Dijk (2002), Van Dijk and Bruijnzeel (2003, 2004bc) and Van Dijk *et al.* (2004d).

Water and nutrient budgets were established for a rain-fed mixed cropping system with maize and cassava, and for a 3-year-old stand of fast-growing Albizia (*Paraserianthes falcataria*) trees. Where possible, water budgets were based on measurements of rainfall, rainfall interception, micro-meteorology, surface runoff and soil hydrology (Van Dijk and Bruijnzeel, 2001; Van Dijk *et al.*, 2004a). Changes in vegetation biomass were measured through

Table 1. Cikumutuk catchment sediment budget for 1995/1996 (after Van Dijk *et al.*, 2004d) (na = not applicable). Note that the estimate of rain-fed bench terrace sediment generation rate (by subtracting all other terms from measured catchment yield) is somewhat higher than that based on direct observations (70 t ha^{-1}) for this year.

Land use	area (ha)	fraction of catchment (%)	sediment generation (t)	fraction of catchment sediment yield (%)	sediment generation rate (t ha^{-1})
rain-fed bench terraces	93	74	7500	82	81
settlements, trails, roads	12	10	1000	11	83
bank erosion and back-cutting	na	na	700	8	na
dense vegetation	5	4	25	0.3	5
paddy rice fields	15	12	-25	−0.3	-2
Cikumutuk catchment	*125*	*100*	*9200*	*100*	*73*

sampling and surveys, and concentrations of various nutrients (including carbon) in soils, eroded sediment, biomass (including harvested crops) and water budget components were analysed to estimate the corresponding nutrient stores and fluxes (Van Dijk *et al.*, 2004bc; Van Versseveld, 2000; Vernimmen, 2001). The results were used to assess the likely direction and magnitude of changes in hydrology and nutrient budgets associated with changes in land husbandry.

A micro-level socio-economic analysis of smallholder agriculture was made in and around the study catchment in 1996 based on fixed and semi-structured interviews. For a general farm survey, interviews were held with 257 out of the 387 households in the municipality that included the study catchment. The questionnaire focused on household composition, economic status, farm holding size, land tenure, income sources and seasonal migration. This was followed by an in-depth survey and discussion among 32 randomly selected respondents addressing farm management and agricultural practices, gender division of labour, views on soil degradation, loss and conservation, and farm and household economics. The results were presented in Purwanto (1999); a follow-up survey was held in 2000 to identify whether important shifts in farm economic and attitudes had occurred (unpubl.).

Results and Discussion

Catchment sediment budget

Most sediment in the Cikumutuk River was derived from the cropped bench terraces rather than from other land use types or the hillslope drainage network (trails, rills and gullies) (Table 1). Annual variation in sediment yields from the rain-fed hillsides was estimated to range between 11 and 70 t ha^{-1} (six years) with a mean of 40 t ha^{-1} (Van Dijk *et al.*, 2004a). The amount of sediment (temporarily) stored in the hillslope drainage network was very limited (typically <4 t ha^{-1}) and sediment delivery ratios (the fraction of all sediment generated on the bench terraces reaching the main stream) were close to unity even on an annual time scale. This implies that any reduction in ‘on-site’ soil loss brought about by soil conservation measures can be expected to show up quickly as reduced ‘off-site’ catchment sediment yields.

Sediment generation on bench terraces and effectiveness of various soil conservation measures

A large proportion of the soil lost from individual terrace units originated from the steep (often bare) terrace risers, and was principally detached and transported initially by rain splash. Many terraces presently lack appreciable soil conservation management and both measurement and modelling indicated that considerable reductions in soil loss could be achieved in principle. Protecting the bare terrace risers with vegetative cover (grass, herbs) was estimated to reduce erosion from these areas from a (longer term and area-weighted) mean of ~200 to ~60 t ha^{-1} yr^{-1} (a 70% reduction; Table 2). Application of surface mulch or denser vegetative cover was estimated to reduce soil loss from poorly managed terrace beds from a mean of ~80 t ha^{-1} yr^{-1} to ~15 t ha^{-1} yr^{-1} (−80%). Different soil conservation measures had a selective impact on the size distribution of the eroded material. Conservation measures that focused on the terrace toe drain (such as the construction of a sediment threshold (‘tied ridging’) or ‘silt pit’, and the application of mulch in the drain) most affected the entrainment and transport of coarser soil aggregates but were less effective in stopping the finer particles. Fine sediment not only constituted roughly half of the sediment lost from poorly managed bench terraces but was also enriched in nutrients. To reduce loss of this finer material

Table 2. Observed mean and range of annual surface runoff coefficient (i.e. as percentage of rainfall), soil loss, the percentage of fine sediment, and annual transport (per unit length of terrace drain, indicating the relative contribution to total terrace sediment generation) for terrace risers, beds and units and various forms of management (from Van Dijk and Bruijnzeel, 2004b).

Treatment	Runoff coefficient (%)	Annual soil loss (t ha^{-1} yr^{-1})	Fraction fine sediment (%)	Transport (kg m^{-1} yr^{-1})	Plot-years
Terrace riser					
little or no protective cover	19 (8-30)	200 (59-393)	6 (3-13)	16 (5-22)	10
well-established cover	8 (1-16)	62 (1-100)	8 (2-24)	5 (0.1-11)	10
Terrace bed					
bare soil	22 (16-27)	94 (71-118)	21 (19-24)	22 (16-30)	4
clean-weeded cassava	25 (13-36)	80 (30-123)	20 (17-23)	19 (7-29)	8
mixed crops	9 (0.1-24)	15 (1-31)	31 (16-48)	4 (0-8)	8
Terrace unit					
with bare riser	13 (6-23)	59 (2-148)	43 (16-95)	na	8
with riser protection	12 (4-26)	31 (8-74)	25 (14-37)	na	5
with riser protection and SWC in drain	9 (6-13)	9 (6-13)	89 (81-100)	na	3

protection of the terrace bed and riser surfaces against rainfall impact is needed, for example by establishing low, dense and semi-permanent vegetation (such as grass, scrubby herbs or fruit-producing vines) on the risers, and by surface mulching on the terrace beds. These measures also reduce the loss of coarse material. On the basis of our field measurements a combination of the above-mentioned measures can be expected to result in an up to six-fold reduction in overall soil loss: from an average ~60 t ha^{-1} yr^{-1} for poorly managed bench terraces to ~10 t ha^{-1} yr^{-1} for terraces with appropriate conservation management (Table 2). Comparing these findings for individual terraces with measurements made at larger scales suggested that an up to four-fold reduction of stream sediment loads should be feasible, i.e. from the current estimated annual average of ~40 t ha^{-1} to 10—15 t ha^{-1}.

Impacts of changes in land husbandry on hydrology and nutrient budgets

Most surface runoff was generated on the compacted terrace drains and on steep, bare terrace risers, whereas risers with a well-established protective plant cover produced little surface runoff even during the largest storms. Similarly, mulching and low, dense crops such as groundnut reduced runoff from the terrace beds to 0—11 % of rainfall compared with 22—25% for bare or poorly managed beds. Surface runoff from (poorly managed) rain-fed bench terraces was an important contributor to peak flows in the Cikumutuk River (together with housing areas and compacted trails). Therefore, conservation measures resulting in better surface cover and less overland flow can be expected to also reduce peak flows at the larger scale. Impacts on the annual water balance were estimated from micro-meteorological and rainfall interception studies. The annual water use of the crops was estimated at 1228 mm, which is intermediate between values generally found for grassland (750–1070 mm) and forests (1350–1500 mm) in the humid tropics (Van Dijk *et al.*, 2004a). Evaporation from the wet soil made up a significant fraction of total evapotranspiration and mulch application is likely to reduce total water use. By contrast, an increase in tall, deeper-rooted permanent vegetation (such as plantations) is likely to increase water use since trees continue to extract water from the soil throughout the dry season.

The carbon budget for the rain-fed mixed cropping system was strongly negative, with losses of 1.5—4.1 t C ha^{-1} yr^{-1}. Eroded sediment contributed 0.9 t C ha^{-1} yr^{-1} to overall carbon losses; but most carbon was lost in harvested crops (2.7 t C ha^{-1} yr^{-1}). These losses were not compensated by inputs from manure and atmospheric deposition (combined <0.04 t C ha^{-1} yr^{-1}) or net CO_2 assimilation. By contrast, the Albizia plantation showed a strongly positive carbon budget, sequestering 8.9 t C ha^{-1} yr^{-1} in biomass alone. Although the soil sampling in the forest was not too rigorous, the results indicated soil carbon accumulation rates of several t C ha^{-1} yr^{-1} as well as large increases in soil nitrogen content. Budgets for other major nutrients suggested a steady depletion of the cropped soil, but results were uncertain for the plantation. Although the loss of well-structured topsoil may be mitigated by soil conservation, this is unlikely to reverse the decline of available soil nutrients. Preliminary field observations suggested that surface mulching on the terrace beds even suppressed crop growth, possibly because of 'nitrogen-robbing' associated with decomposition of the nitrogen-poor harvest residues used. More research is needed to better understand the nutrient dynamics of the mixed cropping system and ways in which these may be optimised agronomically.

Socio-economic analyses

The political and economical situation of upland farming in West Java has been and remains unfavourable for soil conservation. The micro-scale study suggested that farmers have to cope with insecure land tenure, small holdings, deficient economic support systems and a lack of appropriate farming technology (Purwanto, 1999). This has caused many to rely on seasonal off-farm employment outside their home areas. As a result, farmers typically minimise capital and labour investments in their farming operations, with adverse consequences for investments in soil conservation. A soil conservation project launched in the area between 1986—1989 with international support had little lasting impact. The large, direct subsidies provided to the farmers led to an over-emphasis on mechanical solutions (such as bench-terracing) but neglected their maintenance requirements. Gully 'plugs' constructed at the time ceased to function within a few years. The project also served as a disincentive to use less expensive measures which might have been adopted spontaneously by the farmers otherwise. Instead, after the project was terminated, farmers abandoned many of the introduced measures and a considerable proportion of the bench terraces was poorly maintained at the start of CHERP in 1994 (Purwanto, 1999).

The follow-up survey in 2000 (unpubl.) suggested a further movement towards income sources other than rain-fed cropping. Farmers identified a decrease in rain-fed crop productivity, and erosion and general soil degradation as its main cause. The effectiveness of soil conservation measures (vegetating terrace risers, mulching, and constructing sediment thresholds or silt pits in the terrace drains) in reducing soil loss was widely acknowledged, but spontaneous adoption was limited. The main reason was the required labour investment, but in the case of revegetation and mulching farmers also voiced concerns about its impact on crop productivity through increasing pests and nutrient competition. Occasional observations indicate that since 1994 the conventional maize-cassava-based cropping system is being replaced by other land uses. These include more intensive cultures such as ginger and chillies, small-scale plantation forests and fallow land (often invaded by *Imperata* grass or scrubs).

Conclusions

Central to the causes of, and solutions to environmental problems in the Cikumutuk area is the low level of revenue currently generated from cassava-maize based rain-fed cropping. The market price of cassava has plummeted over the last decade, with 2001 international cassava prices being less than half of 1995 levels (FAO/GIEWS, 2001). Characteristically, in 1998 the farm gate price per unit dry mass of marketable cassava was only twice that of manure. Most available resources are therefore invested elsewhere. The prevailing insecurity of land tenure presents a further major impediment to widespread adoption of better land husbandry practices. Arguably, two contrasting strategic options are available in order to address the current situation: de-intensification and intensification of land use.

The establishment of plantation forest or natural regrowth was seen to decrease surface runoff and sediment generation and therefore, in principle, de-intensification can provide a solution to on-site and downstream sediment problems. Conventional fallow systems do not seem sustainable given the mounting population pressure, however. Fields are often left fallow for one or two years after three to five cropping seasons in order to regain some degree of fertility. These typically short fallow periods are too short for substantial soil restoration and fodder is often cut on such fields, favouring the establishment of grasses with low nutritional value such as *Imperata cylindrica*. Soil fertility may be restored to some extent by afforestation, depending on the species involved and the 'improved' fallow period. Albizia trees rapidly enhanced soil carbon and nitrogen contents, although the possible consequences for other soil nutrients (potassium, calcium, phosphorus) and soil acidity require more attention (Bruijnzeel and Wiersum, 1985; Binkley and Giardina, 1997). Plantation forest can also provide income through the sale of timber and fuel wood after some years, but potential constraints to afforestation include the lack of rapid benefits, the tree stumps that impede tillage after clear-felling, and the possibility of pest outbreaks (as occurred previously for the widely adopted 'miracle tree' *Leucaena*).

The alternative is to try and simultaneously reduce environmental problems and enhance land productivity through intensification. Although promoted unsuccessfully in the study area in the past, intensification on rain-fed land through agro-forestry (involving fodder crops for stall-fed livestock) still seems viable (Tanner *et al.*, 2001). Past efforts to improve use of the land in the study area have failed mainly since they did not meet the primary objectives, problems and possibilities of farmers. One way to address this is by co-operating with farmer innovators and by information exchange between farmers, e.g. during farmer-to-farmer visits. Promising developments are the spontaneous local use of a shrubby herb (*Gendarussa vulgaris*) for fodder and terrace riser cover and, elsewhere in the Cimanuk River basin, the creation of farmer co-operatives producing fruit, vegetables, fodder and other cash-generating products using organic farming methods. However, without first improving the land tenure situation there is little hope that even the finest technical solutions will last. More effort should therefore be directed towards assisting farmers in improving this situation, for example by looking for ways to strengthen relevant local non-governmental organisations. Only such an integrated approach - involving both people and the environment - can be expected to lead to better management of land and water, thereby beginning to reverse the spiral of unsustainable agriculture that continues to threaten the livelihood of the many people living in Java's uplands.

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References

Binkley, D. and Giardina, C. (1997). Nitrogen fixation in tropical forest plantations. In "Management of Soil, Nutrients and Water in Tropical Plantation Forests", Nambiar, E.K.S and Brown, A.G. (Eds.). ACIAR Monograph 43.

Bruijnzeel, L.A. and Wiersum, K.F. (1985). A nutrient balance sheet for Agathis dammara Warb. plantation forest under various management conditions in Central Java, Indonesia. *Forest Ecology and Management* 10, 195-208.

FAO/GIEWS (2001). Food Outlook - global information and early warning system on food and agriculture. *Food Outlook* 4, 11 (*http://www.fao.org/docrep/005/y6027e/y6027e03.htm*)

Purwanto, E. (1999). Erosion, Sediment Delivery and Soil Conservation in an Upland Agricultural Catchment in West Java, Indonesia: A Hydrological Approach in a Socio-Economic Context. PhD Thesis, Vrije Universiteit, Amsterdam, 218 pp.

Tanner, J.C., Holden, S.J., Owen, E., Winugroho, M. and Gill., M. (2001). Livestock sustaining intensive smallholder crop production through traditional feeding practices for generating high quality manure-compost in upland Java. *Agriculture, Ecosystems and Environment* 84, 21—30.

Van Dijk, A.I.J.M. (2002). Water and Sediment Dynamics in Bench-terraced Agricultural Steeplands in West Java, Indonesia. PhD Thesis, Vrije Universiteit Amsterdam, 384 pp.

Van Dijk, A.I.J.M. and Bruijnzeel, L.A. (2001b). Modelling rainfall interception by vegetation of variable density using an adapted analytical model. 2: Model validation for a tropical upland mixed cropping system. *Journal of Hydrology* 247, 239—262.

Van Dijk, A.I.J.M. and Bruijnzeel, L.A. (2003). TEST (Terrace Erosion and Sediment Transport) model: a new tool for soil conservation planning in bench-terraced steeplands. *Journal of Environmental Software and Modelling* 18, 839—850

Van Dijk, A.I.J.M. and Bruijnzeel, L.A. (2004a). Runoff and soil loss from bench terraces. 1. An event-based model of rainfall infiltration and surface runoff. *European Journal of Soil Science* (in press).

Van Dijk, A.I.J.M. and Bruijnzeel, L.A. (2004b). Runoff and soil loss from bench terraces. 2. An event-based model of erosion and sediment transport. *European Journal of Soil Science* (in press).

Van Dijk, A.I.J.M., Bruijnzeel, L.A. and Eisma, E.H. (2003a). A methodology to study rain splash and wash processes under natural rainfall. *Hydrological Processes* 17, 153—167.

Van Dijk, A.I.J.M., Bruijnzeel, L.A. and Wiegman, S.E. (2003b). Measurements of rain splash on bench terraces in a humid tropical steepland environment. *Hydrological Processes* 17, 513—535.

Van Dijk, A.I.J.M., Bruijnzeel, L.A. and Schellekens, J. (2004a). Water budget of inter-cropped maize and cassava on bench terraces in Indonesia. *Agricultural and Forest Meteorology* (in press).

Van Dijk, A.I.J.M., Bruijnzeel, L.A., Vernimmen, R. and Purwanto, E. (2004b). Environmental benefits of establishing fast-growing plantation forest on former cropping land in upland West Java, Indonesia. *Bois et Forêts des Tropiques* 279, 73—78.

Van Dijk, A.I.J.M., Bruijnzeel, L.A., Vernimmen, R. and Purwanto, E. (2004c). Soil loss and the carbon budget for mixed crops and a plantation forest in upland West Java, Indonesia. In "Soil Erosion and Carbon Dynamics", Roose, E., Lal, R., Barthès, R. and Feller, C. (Eds.). *Advances in Soil Science* (in press).

Van Dijk, A.I.J.M., Bruijnzeel, L.A., Vertessy, R.A. and Ruijter, J. (2004d). Runoff and sediment generation on bench-terraced hillsides: measurements and up-scaling of a field-based model. *Hydrological Processes* (in press).

Van Versseveld, W. (2000). Inputs and outputs of nutrients in a terraced rainfed mixed cropping system in upland West Java, Indonesia. MSc Thesis / CHERP Working Paper 15, Vrije Universiteit Amsterdam, 69 pp.

Vernimmen, R. R. E. (2001). A comparative study of biomass, water and nutrient dynamics in mixed cropping, albizzia plantation forest and Imperata grassland on bench-terraced hillslopes in volcanic upland West-Java, Indonesia. MSc Thesis / CHERP Working Paper 16, Vrije Universiteit Amsterdam, 103 pp.