# CROPPRO – Sustainable agriculture in a clean environment:

# Final Report

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**Executive Summary**

This report summarises the work done between April 2005 and December 2004 on this collaborative 3-year CROPPRO project in Tonga supported by NZAID. This final report includes analysis and modelling of the results and identification of alternative fertiliser practices to minimise contamination of water resources. It highlights the Participatory Rural Assessment (PRA) work carried out, and the provision of a Decision Support Tool (the CROPPRO Calculator) to improve pesticide practices so that Tonga's soil and water resources are not compromised by the agrichemical practices used in squash pumpkin production.

CROPPRO is collaboration between this NZAID project and a multinational EU-funded project based in Samoa, Tonga, and Fiji.

In brief:

- We participated in a meeting in Samoa with our EU partners during July, and we carried out Participatory Rural Assessments in Tonga in October. From our participatory discussions in Tonga, a consensus was achieved to develop a Decision Support Tool that would enable growers to match pesticide choice and practice with local conditions. As well, we outlined alternative fertiliser practices that should limit the leaching of nitrogenous fertiliser into the freshwater lenses, lagoon and fringing reef.

- We found that the water leaving the rootzone of the squash pumpkin is at about 3-6 times above the drinking water standard for nitrate. There is evidence, from the quality of the water entering the lagoon, that fertiliser nitrogen is leaching under the crop into the fresh water lenses, and then into the lagoon, and probably into the fringing reef, as well. Sustainable fertiliser practices have been proposed, and these were refined following discussions with local experts.

- Modelling of the crop and soil water balances was carried out, and the results of these have been written up in several publications. This modelling formed the basis for developing a Decision Support Tool to select the best agrichemical practices to protect Tonga's soil and water resources.

- We developed the Decision Support Tool, called the CROPPRO Calculator, and this CD-based software provides interactive information on the best choice of pesticides for local conditions and the practices to minimise leaching and avoid soil build-up. Copies of the installable CDs were despatched to Tonga in December. A copy is included with this report

- The outcomes of this 3-year project will be:

    - Improved efficiency of fertiliser use and reduced nutrient leaching into Tonga's water resources
    - Sustainable pesticide practices for protecting Tonga's fresh-water resources and fringing reef from agrichemical leaching, and for avoiding build-up of chemicals in the soil

- Improved awareness by the Tonga growers and community of the link between land management and Tonga's receiving-water environments.
- An expansion of an awareness throughout the Pacific, initially through CROPPRO, of the fragile nature of atoll ecosystems, and the development of tools to encourage implementation of sustainable land-use practices
- Increased collaboration with our CROPPRO EU partners on aid and development projects around the world

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## Background and Purpose

The European Union-sponsored CROPPRO project aims to provide assistance to Pacific Island countries by the development of integrated farming approaches for sustainable crop production in environmentally constrained systems. The project specifically addresses the relationship between agricultural activities and the surrounding environment, and focuses on the development of tailor-made farming approaches for major crop/soil units aimed at maximising agricultural production, and minimising environmental deterioration with its social and health implications. Special attention is paid to knowledge transfer and participatory, culture-sensitive training for stakeholders and end-users. These aims will be met through related, but independent, research projects in Fiji, Tonga, and Samoa in collaboration with local researchers, landowners and users, and government and non-government bodies. While the majority of the CROPPRO project is funded by the European Union, HortResearch's involvement was supported by NZAID.

A "kick-off" meeting was held 3 years ago n November 2001 and included representatives from the larger EU project, namely:

- Alterra (The Netherlands),
- Université catholique de Louvain (UCL, Belgium),
- HortResearch (New Zealand),
- University of the South Pacific (USP, Samoa),
- Ministry of Agriculture and Forestry (MAF, Tonga),
- Ministry of Agriculture, Sugar & Land Resettlement (MASLR, Fiji),
- Matuaileoo Environment Trust Incorporated (METI, Samoa), and
- Eco-Consult Pacific (Fiji and Tonga).

During that meeting it was decided that HortResearch would concentrate its research efforts in Tonga, in collaboration with MAF and UCL, where the environmental consequences of squash production was of considerable some concern. This final report, the last in a series of 6, details the concluding Participatory Rural Assessment (PRA) activities of the project, and outlines the alternative fertiliser practices proposed, and the Decision Support Tool that was developed for better selection of pesticides, and development of better practices.

Sustainable Squash Production

Protected Environment

## Progress Against Milestones

We have now concluded this 39-month project. Details of the milestones and their achievement are given in Appendix 1, and a summary is contained here. All milestones have been achieved. During PRA (participatory rural appraisal) actions in our visit to Tongatapu in October 2004, we outlined the impact that fertiliser practices were having on the nitrogen leachate leaving the rootzone, and its arrival in the lagoon. Through participatory discussions, improved fertiliser practices were suggested. Also it was agreed that we would develop a CROPPRO Calculator, as a Decision Support Tool, for choice of sustainable pesticide practices. Our preliminary modelling had shown that many pesticides were capable of leaching through the soil to the groundwater lens, the lagoon, and fringing reef. A CD-ROM of the Calculator was despatched to participants during the week prior to Christmas 2004. A copy of the CD-ROM is enclosed with this report. These actions concluded the project's activities, and this final report completes our contractual requirements.

## Participatory Rural Appraisal

A full CROPPRO partners' meeting was held in Samoa in July to outline the progress to date on technical matters and the PRA initiatives, not only in Tonga, but also in Samoa and Fiji where our EU partners are also working. Brett Robinson of HortResearch attended this meeting and his report is appended here as Appendix 3.

During the week 18-24$^{th}$ October 2004, the HortResearch team of Brent Clothier, Steve Green and Carlo van den Dijssel travelled to Tongatapu to carry out PRA activities, and seek agreement for development of a Decision Support Tool to allow growers and squash exporters to develop sustainable pesticide practices. Viliami Manu of MAFF Tonga organised a schedule of meetings to discuss how the project would deliver its findings.

*The PRA Scedule*
Tuesday 19$^{th}$ October
Morning: Meeting with MAFF staff at Vaini to set up PRA plans with Viliami Manu
Afternoon: Meteorological Section, Ministry of Civil Aviation, Discuss modelling objectives and obtain long-term weather data for Tongatapu to be used in risk-assessment modelling.

Wednesday, 20$^{th}$ October
Morning: Open Workshop, Vaini Station, More than 50 people; including growers, scientists, extension staff, and students from the Tonga Institute of Higher Education (TiHE). Interviews with Tongan national TV
Afternoon: Meetings with two squash-packhouse owners; one at Nukunuku and the other at the Port.

Thursday, 21$^{st}$ October "Training the trainers"
Vaini: Meetings with Kamilo Ali (MAFF and Development of Sustainable Agriculture in the Pacific), Pila Kami and Suitoni Tupou (MAFF entomologists), and Luseana Taufa (MAFF plant pathologist)

Friday, 22$^{nd}$ October, 2004 "Engaging the Stakeholders"
Morning: Meeting with Jonathan Curr, Deputy High-Commissioner, NZ High Commission
Meeting with the Tonga Trust - Tevita Vae'ila and 'Ofa Fa'anunu, Pesticides Awareness & Sustainable Agriculture, Tonga Trust, and NGO

Afternoon: Meeting with the Honourable Tuita, Minister of Agriculture, Forestry & Food, Kingdom of Tonga.
Visit to a squash-packhouse at Vaini

*PRA Workshop*
Over 50 people attended the project workshop on the morning of Wednesday, 20th October (Figure 1).

**Figure 1: The CROPPRO workshop chaired by Mr Finau S. Pole (MAFF, Chief Agronomist) with prominent grower Mr 'Otenili Tu'iulotu on his left.**

At this workshop, on behalf of the HortResearch team, Brent Clothier presented the findings of the 3-year project, which highlighted the risk of fertiliser nitrogen draining through the rootzone and eventually contaminating the lagoon and fringing reef. The possibility of alternative practices was discussed, and this would ideally see no nitrogenous fertiliser applied at planting. Rather, fertiliser would only be applied once the crop's leaf area had developed, and the root system had become more extensive, so that the fertiliser would be less prone to leaking out the bottom of the rootzone.

Viliami Manu translated the talks into Tongan (Figure 2). Dr Manu also commented that if no N fertiliser were applied at planting, there still might need to be some phosphatic fertiliser to be applied to provide initial nutrients for the growth of the squash.

Brent Clothier also outlined how pesticides, like fertilisers, can move through the soil, and could end up in the fresh-water lenses. He noted that in a recent project in New Zealand, HortResearch had developed a GROWSAFE® Calculator as a Decision Support Tool (DST) for growers and the industry to develop better pesticide practices, and permit site-specific selection of the best pesticides to minimise leaching and avoid the build-up of residues in the soil. The meeting agreed that it would be worthwhile for such a DST to be developed for Tonga. It was decided that HortResearch would develop a CROPPRO Calculator DST for Tonga

**Figure 2**. **Participants at the CROPPRO workshop at Vaini, and the presentation by Dr Viliami Manu of MAFF.**

**Figure 3. Drs Viliami Manu (MAFF Tonga) and Brent Clothier (HortResearch) being interviewed by Tonga TV.**

Tonga TV attended the workshop, and following the meeting they interviewed both Viliami Manu and Brent Clothier (Figure 3).

As well as the workshop, the CROPPRO team visited three packhouses, and also met with the NGO of the Tongan Trust who are conducting an extension programme of Pesticides Awareness in Sustainable Agriculture (PASA). The Tonga Trust were very supportive of our proposal to develop a CROPPRO Calculator for Tonga. Also the CROPPRO team met with Mr Jonathan Curr, New Zealand's Deputy High Commissioner to Tonga, and finally they met with the Honourable Tuita, the Tongan Minister for Agriculture, Forestry, Fisheries and Food (Figure 4). He encouraged us to develop a DST for better selecting pesticide type and choosing better pesticide practices for squash pumpkin production in Tonga (Figure 4).

**Figure 4. The CROPPRO team met with the Honourable Tuita, Minister of Agriculture, Forestry, Fisheries and Food.**

The concluding aspects of this CROPPRO project were carried out back in New Zealand. This focussed on development of the CROPPRO Calculator, a DST for enabling growers and exporters to select the best pesticides and best practices to protect Tonga's fragile soil and water environments.

**Sustainable Fertiliser Practices Proposed**

A prime concern with agrichemical usage in squash pumpkin production is that leaching will carry the chemicals through the rootzone of the squash, down into the underlying fresh-water lenses, and then into the lagoon or out into the fringing reef

A series of 6 springs discharging into the central lagoon of Tongatapu were regularly sampled at low tide, and the nitrate and ammonium concentration of the samples were determined.

The results from this sampling were given in the last report (#5), and here we just highlight our findings.

In Figure 5, on the left, can be seen one of the freshwater springs entering the lagoon. This was one of the sampling sites. On the right of Figure 5 is shown the seasonal trend of ammonium-nitrogen in the spring water entering the lagoon. The impact of the planting application of fertiliser on day-of-year (DOY) 185-190 is dramatic, and it is even possible to detect a rise in ammonium following the fertiliser application on DOY 255

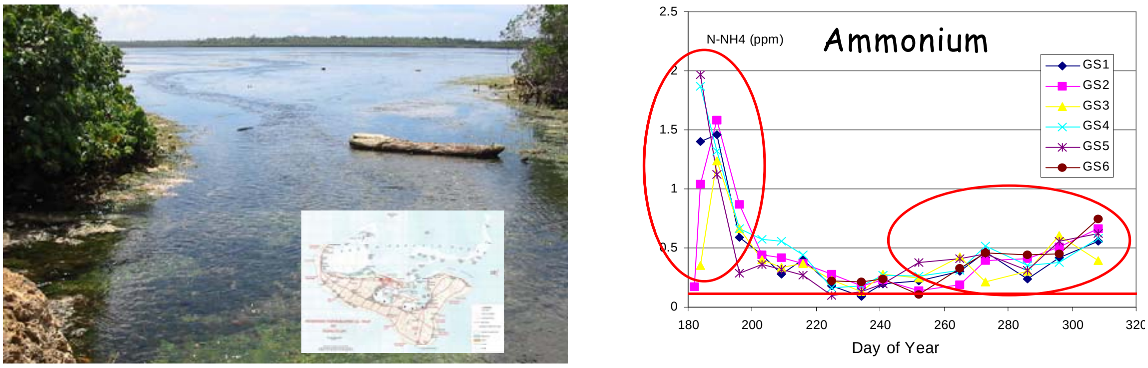


**Figure 5. One of the six freshwater springs entering the lagoon (left) from which regular samples were collected for ammonium analysis (right)**

This evidence of leakage from the rootzone of squash pumpkin was corroborated by our measurements of the level of nitrogen in the leachate immediately under the rootzone (Figure 6). In Figure 6, on the left, can be seen one of the fluxmeters we used in our squash pumpkin plots to monitor both the quantity of drainage, and the quality of the leachate in terms of nitrogen. The nitrate level in the leachate, at about 50 ppm, is five times the WHO limit for drinking water.

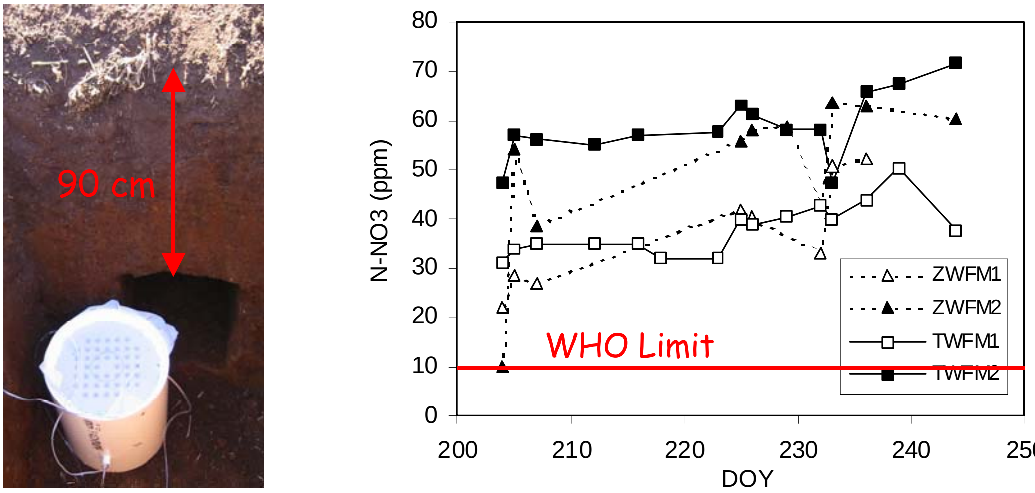


**Figure 6. One of the fluxmeters (left) used to measure drainage and the leaching of nitrates under our squash pumpkin plots, and the concentration of nitrate in the leachate is shown on the right.**

Thus there is evidence that high levels of nitrate are leaching from the rootzone of the squash pumpkin, and there is also a strong suggestion that the high levels of ammonium we observed leaking into the lagoon come from the planting application of fertiliser to the squash.

We consider it inefficient, wasteful, and polluting to apply fertiliser at planting on DOY 185-190. It is another 50 days before the plants have sufficient roots to take up fertiliser. In those 50 days some 350 mm of rain fell, leading to about 270 mm of drainage which leached all of the fertiliser. Growth during the early stages of plant growth could be sustained by the mineralization of the composting grass that was ploughed in prior to planting. This is shown diagrammatically in Figure 7.

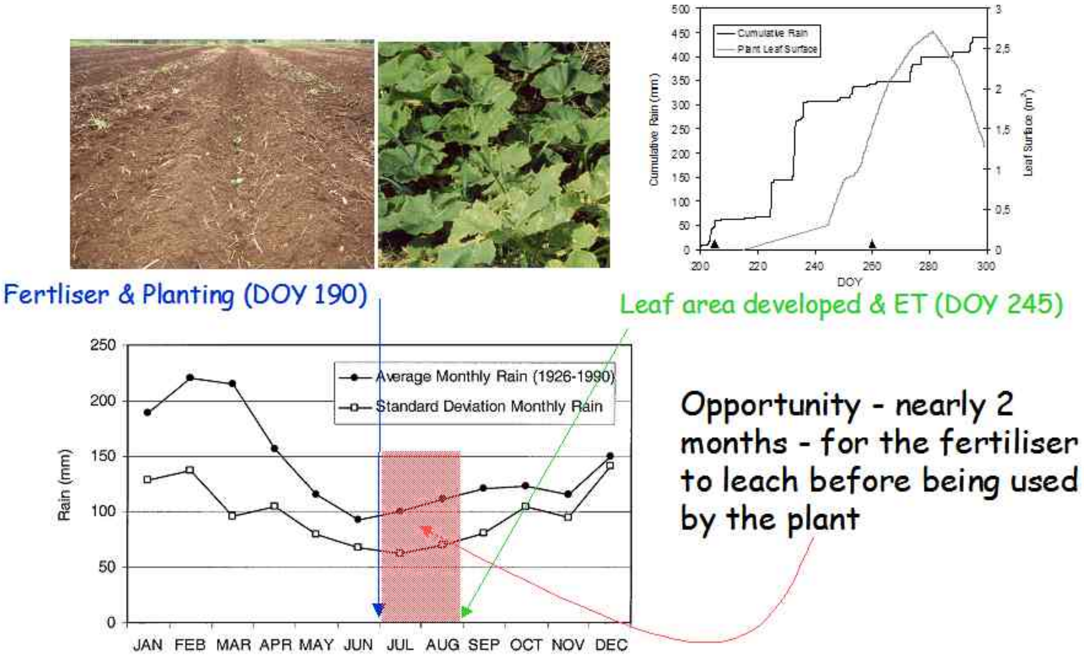


**Figure 7. The fertiliser applied at planting (DOY 185-190) leaches out of the rootzone during the 2 months before the plant is big enough to extract the nutrients. During that time, on average 220 mm of rain falls, and much of this is lost as drainage, which carries with it the fertiliser nitrogen.**

Thus our recommendation is that no planting nitrogen fertiliser be applied. However, it would be worthwhile checking to ensure whether some phosphate is required. In any event, applied phosphate is very unlikely to leach for it becomes strongly bound to the soil.

Not applying nitrogen fertiliser at planting, and relying on mineralization from the ploughed-in grass, would save on fertiliser costs, and would minimise leaching losses to groundwater and the lagoon. This alternative practice would be more economic, and would limit contamination of the freshwater lenses, as well as the lagoon and fringing reef.

Furthermore, we noted that the fertiliser used (Figure 8) contains the heavy-metal impurities of cadmium, lead and mercury. Indeed the fertiliser bag carried health and environmental warnings. Thus the less bag-fertiliser applied, and greater reliance on natural mineralization from the ploughed-in grass, would limit the risks associated with the potential soil build-up of heavy metals in the bagged fertiliser.

The alternative fertiliser strategy proposed would thus have economic benefit, and manifold environmental gains. The proposal of this alternative strategy could only have come from conducting the detailed experiments and modelling carried out under this CROPPRO project.

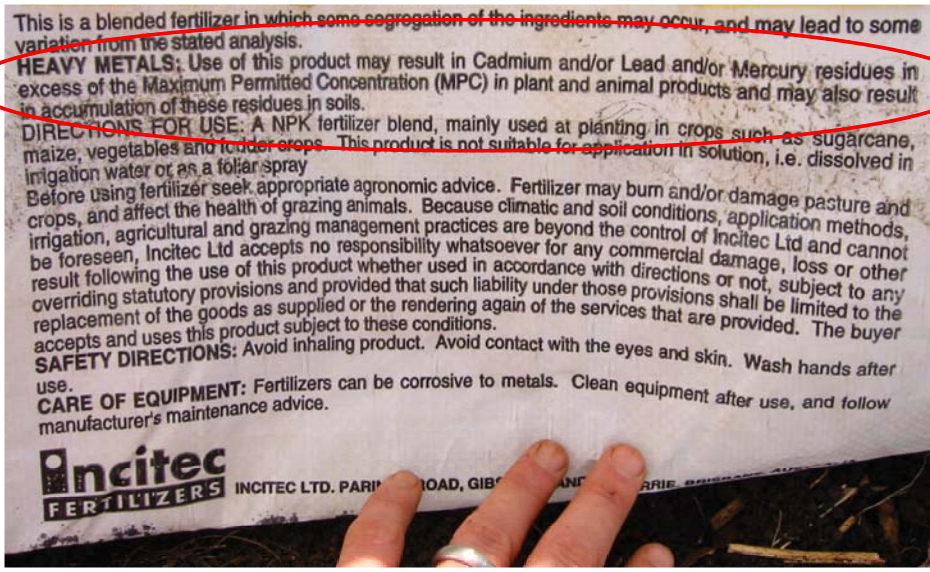


**Figure 8 The health and environmental warning, in relation to heavy metals, contained on the bags of fertiliser used in squash pumpkin production.**

**Choosing Better Pesticides for the Tongan Squash Industry**

The squash industry is an important part of the economy of the Kingdom of Tonga. The cultural practices of squash production require that pesticides be used: herbicides are used to

**Figure 9: In the humid tropical environment of Tonga there is an intimate connection between land management practices and the receiving waters of the subterranean lenses, the internal lagoon, and the fringing reef.**

control weeds and kill grass, fungicides are used to stave off the fungal pathogens that plague this humid tropical climate, and insecticides are used to kill pests.

In the humid tropical environment of Tonga, with plentiful rainfall and permeable soil, pesticides are likely to leach rapidly through the rootzone soil of the squash-pumpkin fields to reach the underlying lenses, the lagoon and fringing reef (Figure 9). In such environments, it is therefore important to choose pesticides that are less likely to leach, and to adopt practices that minimise the opportunities to leach.

Decision-support tools (DST) can be developed to propose the best-fit pesticides for local conditions.

In New Zealand we have just concluded such a project. We have developed a DST calculator that allows growers to match pesticides and their usage to local environmental conditions. This is called the Growsafe® Calculator. At the PRA meeting at Vaini on October 20th, we demonstrated the use of the Growsafe® Calculator for New Zealand conditions. We proposed that we could do the same for Tonga. There was enthusiasm for us to develop such a DST for squash in Tonga. Separately, at our meeting with the Tongan Trust on Friday 22nd October, there was a similar level of support to develop such a DST

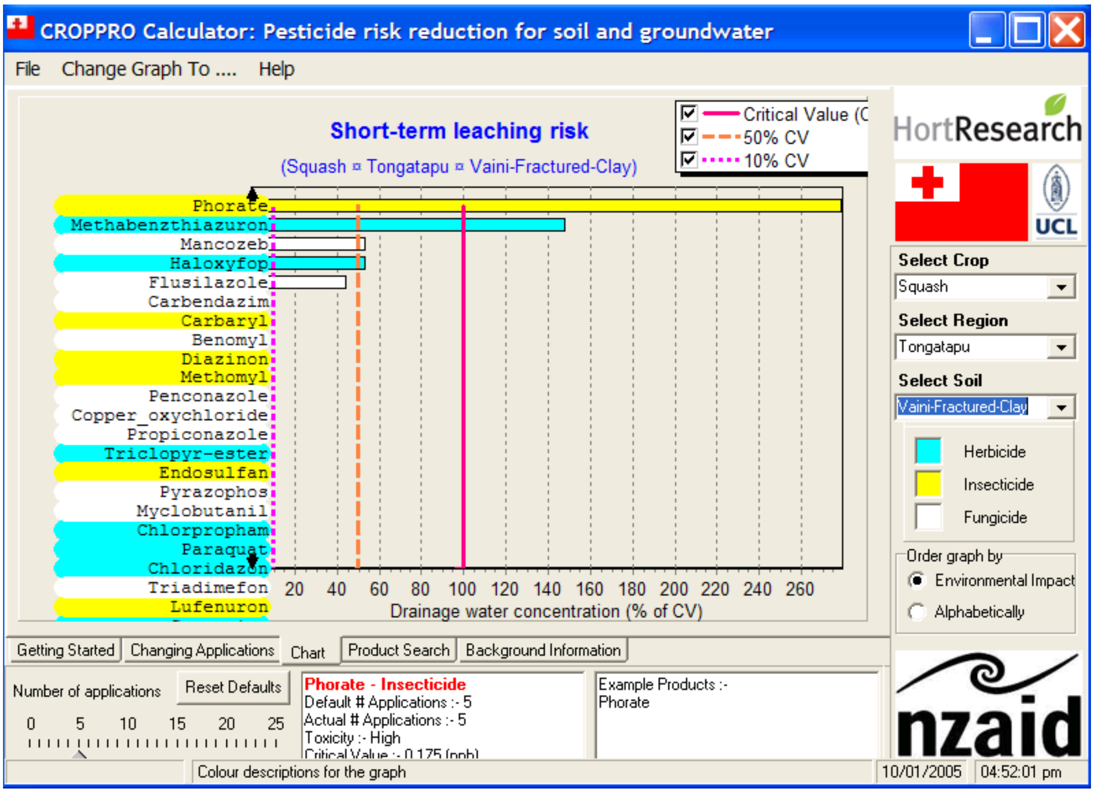


**Figure 10. The CROPPRO Calculator ranks the environmental friendliness of pesticides used on the fractured Vaini clay on Tongatapu. Here it can be seen that the use of 5 applications of phorate poses a significant short-term risk to the underlying groundwater. Other insecticides would be better suited.**

Upon our return to New Zealand, we accessed weather and soil databases to underpin the DST, and we used the field measurements we had made to provide requisite information. MAFF supplied the spray diary practices for the pesticides used in squash pumpkin.

We were then able to rewrite the software code of the Growsafe® Calculator to adapt it to Tongan conditions. The DST was then loaded onto a self-installing CD-ROM. Copies of the CD were despatched to MAFF and stakeholders in Tonga. A copy of the DST is provided with this report.

In Figure 10 is shown the environmental ranking, from worst down to best, of all the pesticides used in squash production on the Vaini fractured clay. Here the measure is in terms of the short-term leaching risk during July to October. Phorate would not be a good choice here for use as an insecticide.

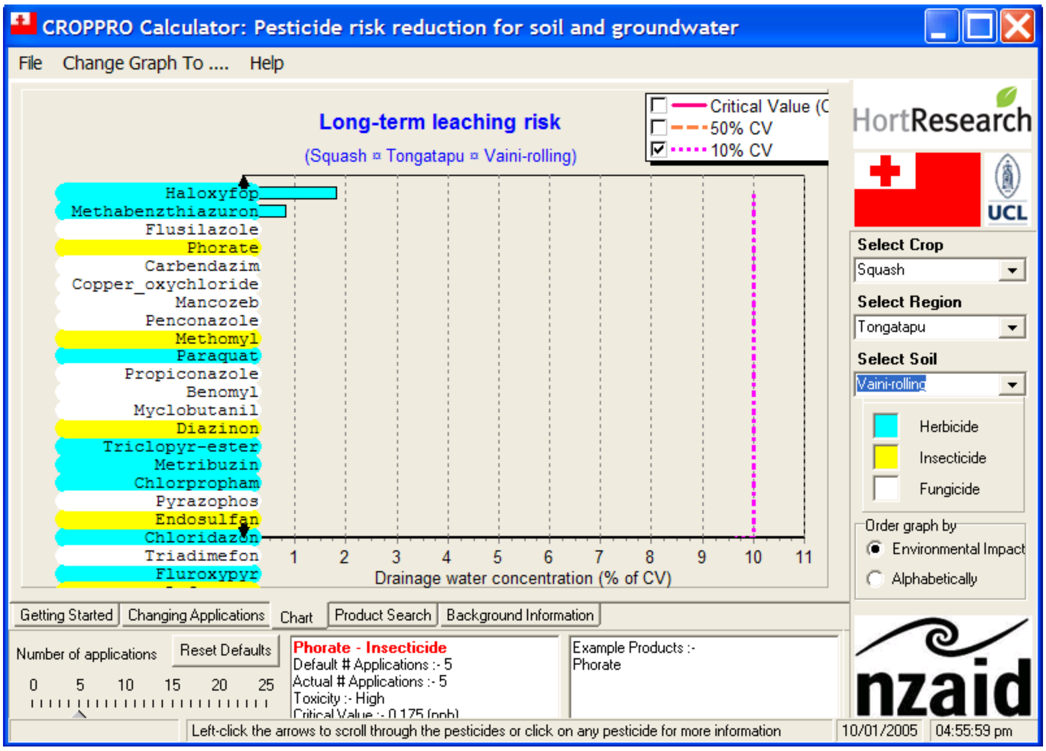


**Figure 11. The CROPPRO Calculator here provides a ranking of pesticides, in terms of long-term leaching risk, for the rolling phase of the Vaini clay.**

In terms of the long-term leaching risk, the annual average, for the rolling phase of the Vaini clay (Figure 11), the herbicide Haloxyfop poses the greatest risk, although it is only a low percentage of the Critical Value, just 2%. Nonetheless, it would still be preferable to choose more environmentally friendly herbicides from lower down the list. Alternatively, it is possible with this DST to explore the impact of using fewer applications of pesticide. The toggle bar on the lower left can be shifted to determine how beneficial it would be to use one, or more, fewer sprays.

There are two environmental risks associated with pesticide use: the chemical might leach to groundwater, or it might build-up in the soil to reach toxic levels.

The CROPPRO Calculator can also provide an assessment of the risk of soil build-up associated with the spray-diary practices of pesticide use in squash production. In Figure 12 is shown the risk of soil build-up for squash production on the rolling phase of the Vaini clay.

As we have found elsewhere, and as is a growing concern around the world, copper-based fungicides can lead to a continuing build up of the metal in the upper layers of the soil.

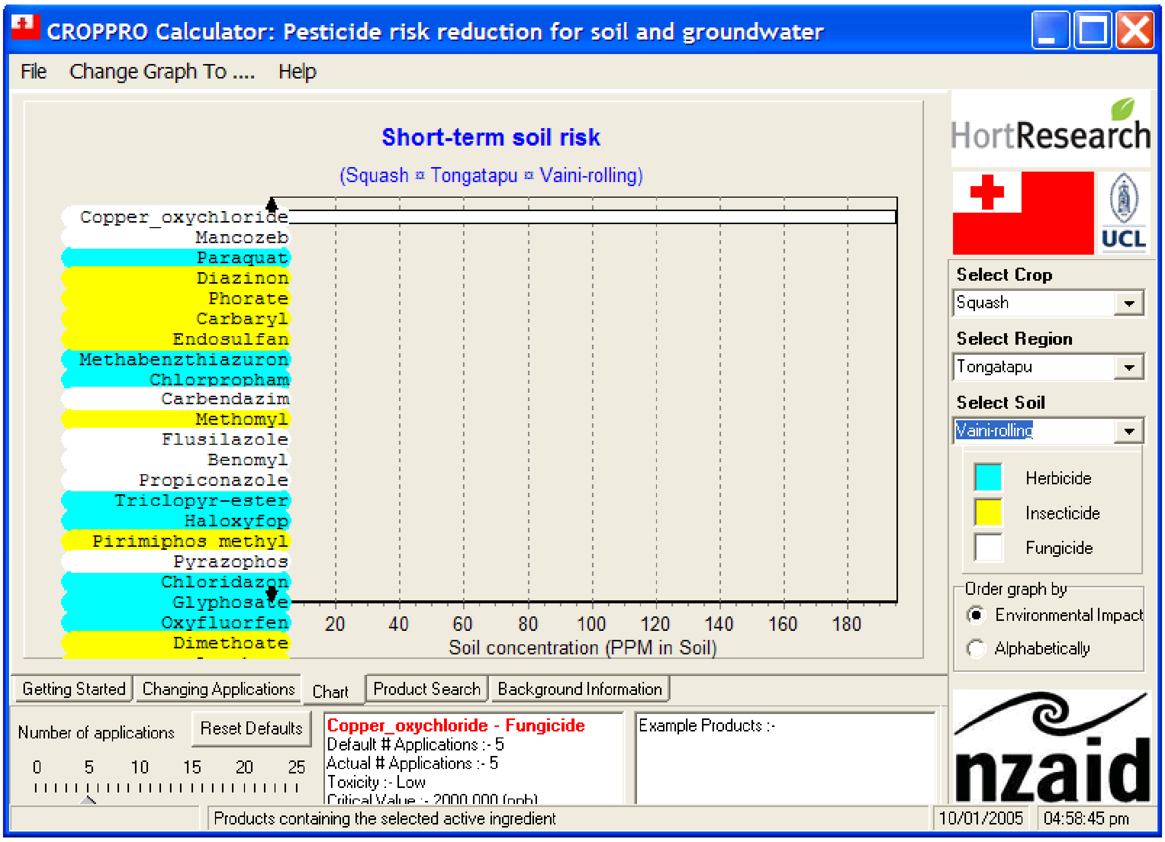


**Figure 12. The CROPPRO Calculator here show that for the rolling phase of the Vaini clay, copper can build-up in the soil to high levels.**

Here the surface soil would likely reach copper levels of around 200 ppm. It is likely that these levels would adversely affect soil microbiological activity, and lead to a decline in soil quality. Care should be taken with the continuing high level of copper-based fungicides.

The CROPPRO Calculator is modular, and the software code is written in such a way that the Calculator can easily be extended to other crops, others soils, and other islands within Tonga, or throughout the Pacific.

## Expected Outcomes of the NZAID-sponsored CROPPRO project

The expected outcomes of this 3-year project will be:

- Improved efficiency of fertiliser use and reduced nutrient leaching into Tonga's water resources
- Sustainable pesticide practices for protecting Tonga's fresh-water resources and fringing reef from agrichemical leaching, and for avoiding build-up of chemicals in the soil
- Improved awareness by the growers and community of the link between land management and Tonga's receiving-water environments.

- An expansion of an awareness throughout the Pacific, initially through CROPPRO, of the fragile nature of atoll ecosystems, and the development of tools to encourage implementation of sustainable land-use practices
- Increased collaboration with our EU partners on aid and development projects around the world

**Outputs**

Several outputs have been achieved over this period. These include:

A presentation was made at the **SuperSoil 2004** Conference in Sydney, Australia on 6th December, 2004. A copy of that paper is attached as Appendix 2 (*Flux meters for quantifying the leaching of agrichemicals on the island of Tongatapu, the Kingdom of Tonga* by Marijn van der Velde, Steve Green, Glendon W. Gee, Brent Clothier, Valerie Snow, Viliami Manu, Vunivesi Menoniti and Marnik Vanclooster).

Two posters were presented at **EuroSoil 2004** in Freiburg, Germany during 4-12 September, 2004. These papers were *Measurements and modeling of water flux through volcanic soil on the island of Tongatapu* by Marijn van der Velde, Glendon W. Gee, Steve R. Green, Marnik Vanclooster and Brent. E. Clothier, and *Measuring and modeling plant transpiration under tropical conditions* by Marijn van der Velde, Steve R. Green, Marnik Vanclooster and Brent. E. Clothier. These posters are reproduced in Appendices 6 and 7.

A paper has been submitted to the journal ***Agricultural and Forest Meteorology*** on the water use of squash pumpkin in Tonga. A copy of the Abstract is listed in Appendix 5 (*Transpiration of squash under a tropical maritime climate* by M. van der Velde, S.R. Green and M. Vanclooster)

An abstract has been accepted for presentation at the upcoming conference on *Integrated* ***Assessment of Water Resources and Global Change: A North-South Analysis*** in Bonn, Germany, during 23-25 February 2005**.** Our paper is entitled *Sustainable development and small island developing states: protecting freshwater resources from agricultural intensification on the coral atoll of Tongatapu* by M. van der Velde, M. Vanclooster, S.R. Green and B.E. Clothier, and is given here in Appendix 4.

Later in 2005, Marijn van der Velde will complete his PhD at the University of Louvain-la-neuve in Belgium on his work in Tonga. His PhD is being supported by the EU component of the CROPPRO project.

**Appendix 1: Detailed Progress Against Milestones**

Below the agreed technical-research milestones are given with commentary of progress to date.

Milestone 1, month 1, (MAF), *Site Selection*: For practical and logistic reasons Vaini Station was selected.

Milestone 2, month 4, (MAF, HR), *Meteorological data collated* : Meteorological data for various sites on Tongatapu has been collected from NIWA.

Milestone 3, *Not applicable for Tonga*

Milestone 4, month 12, (HR, MAF, UCL), *Existing soil maps etc*: Existing information has been retrieved from Landcare in both printed and digital (GIS) format and is now available to both MAF and UCL researchers. In addition Marijn van der Velde and Gregoire Pochet (UCL) have done a considerable amount of work on characterising the hydraulic properties of the soils.

Milestone 5, month 12, (MAF), *Land-use maps*: Maps of the squash pumpkin area have been completed for 2001 (see report December 2001) and 2002 (April 2003 report) have been completed.

Milestone 6, month 8, (EC, MAF), *Information of farming practices*: This information has been collated and is being used in setting the research priorities for the field research.

Milestone 7, month 10, (EC, MAF), *Information on fertilisers and pesticides*: This information has been collected both through an informal survey of farmers (reported in April 2003) and information from the squash companies in Tonga. In addition we have information supplied by the New Zealand company that exports fertilisers and pesticides to Tonga.

Milestone 8, month 15, (EC, MAF), *Farming questioners concluded*: A preliminary survey carried out, and the results are presented here.

Milestone 9, month 6, (MAF, UCL, HR), *Monitoring equipment installed*: The monitoring equipment was installed prior to planting squash for the 2002 season by HR, UCL, and MAF and that equipment was used and maintained during the growing season by UCL and MAF personnel and in the fallow by MAF. HR and UCL personnel will go to Tonga in July 2003 to reinstall equipment as required.

Milestone 10&11, month 8, (UCL, MAF, HR) *Monitoring soil and groundwater*: The soil was monitored both by logging equipment (water content, drainage, and temperature) and point-in-time sampling (water content and mineral nitrogen) several times during the 2002 growing season. A pilot-scale groundwater survey was done in 2002 and this will be intensified in 2003. In addition several sites have been identified where the groundwater seeps into the lagoon. These sites will be subject to intensified monitoring in 2003.

Milestone 12, months 11-21, (UCL, HR), *Hydraulic behaviour interpreted*: Results from the first season have been interpreted and early results published in a conference paper (see attached).

Milestone 13, months 11-24, (MAF, UCL, HR), *Crop monitoring*: Squash development and nitrogen uptake was monitored during the 2002 growth season and will be used to construct nutrient balances. This work will continue for the 2003 season. This work has been completed, and improved fertiliser practices proposed

Milestone 14, months 15-18, (UCL, MAF, HR), *Modelling training*: The principles of modelling and the modelling code of good practice were topics of workshops in Belgium and The Netherlands in March 2003. Personnel from MAF, HR, and UCL attended and contributed to these meetings.

Milestone 15 months 16-18, (HR, UCL, MAF), *Model input files prepared*: This work was initiated during the 2002 season and continued during the workshops in March.

Milestone 16, month 22, (UCL, HR, MAF) *Preliminary risk assessments*: Risk assessment frameworks developed for pesticide usage are the starting point for this work. Weather data and soil information has been compiled. The inputs and ranges for the variables will be refined following completion of the grower surveys (Eco-Consult).

Milestone 17, months 22-30, (UCL, HR, MAF), *2nd years model simulations*: Models of crop water use and soil water drainage have been carried out, and are reported here. A paper abstract has been submitted to an international modelling conference in the Netherlands in October 2004 (Appendix 5)

Milestone 18, month 28, (UCL, HR, MAF), *At-risk areas identified*: Sampling from the lagoon has identified at-risk areas, and shown that nitrogen, as well as pesticides, need to be considered for their ecosystems impact. A paper was published in WISPAS (Appendix 4), and an abstracts submitted to the SuperSoil 2004 conference in Sydney (Appendix 3), and to the *Vadose Zone Journal*.

Milestone 19, month 26, (MAF, EC, HR, UCL), *Cultural practices assessed*: The results of the fungicide trial have identified alternative sprays, and the role of split applications of fertiliser will be assessed for its impact on the leaching of nitrogen.

Milestone 20, month 29, (EC, UCL, HR), *Alternative practices defined*: Alternative sprays, and spray practices, plus improved fertilisers and practices have been defined. These will be delivered under Milestone 23 in Tonga in October 2004.

Milestone 21, month 32, (All), *Alternative practices assessed*: It was suggested that no nitrogen fertiliser be applied at planting, and presentation of these results to growers and extension scientists was carried out at Vaini in October 2004. It was agreed at this meeting that a Decision Support Tool be developed for selecting better pesticides and better practices

Milestone 22, month 34, (All), *Technology packages prepared*: A draft CD-ROM of the Decision Support Tool was prepared in anticipation of the PRA meeting at Vaini

Milestone 23, month 36, (All), *Presentation of packages to stakeholders*: At a meeting at Vaini on 20th October 2005, the proposed alternative practices were described both for fertiliser usage and pesticide practices. A CD-Rom of the CROPPRO Calculator for sustainable pesticide usage on Tongatapu was sent to a number of end-users, NGOs and stakeholders during the week of 20th Decdember 2004. A cope of the CD is enclosed with this report

Milestone 24, month 36, (All), *Report & recommendations*: This final report completes the project.

In addition to the technical milestones there are milestones for the Participatory Learning and Action (PLA) parts of the project. These are given below.

Milestone 25, month 1, (EC, MAF), *Village Coordinating Committees established*:
Milestone 26, month 2+, (EC), *Monthly meetings of VCC*:
Milestone 27, month 6, (EC), *Training curricula developed*:
Milestone 28, month, (EC), *Training the trainers*:
Milestone 29, month 9+, (EC, MAF), *Participatory training*:
Milestone 30, month 12+, (EC, MAF), *Evaluation of training*:

**Appendix 2: The paper published in the Proceedings of the SuperSoil 2004 Conference, Sydney, December, 2004**

SuperSoil 2004 Sydney

3rd Australian New Zealand Soils Conference
University of Sydney, Australia



# Flux meters for quantifying the leaching of agrichemicals on the island of Tongatapu, the Kingdom of Tonga.

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## Abstract

Intensification of agriculture in Tonga, notably through squash-pumpkin production, has lead to increased use of agrichemicals. These agrichemicals, both fertilisers and pesticides, pose a risk to the fragile environment and water resources of the raised atolls of Tonga. We have used water flux meters (WFM) to monitor both the quantity and quality of drainage leaving the rootzone of squash pumpkin growing on Tongatapu. Here we discuss the results from non-suction WFMs in relation to the loss of nitrogen during the establishment phase of the squash. During this establishment of the squash, over days-of-year (DOY) 200-245, some 350 mm of rain fell, and about 70% of this left the rootzone as drainage in this humid environment. The concentration of nitrate-N in the drainage water was around 50 ppm, indicating that not only had the initial fertiliser dressing of 62 kg-N/ha been lost, but also some of N mineralised from the ploughed-in grass had also drained away. Eliminating the initial N-fertilisation at planting would reduce the nitrogen load on the groundwater, and save on fertiliser costs.

## Introduction

The United Nations summit on Sustainable Development in Johannesburg in September 2002 called for the protection of the marine environment from land-based activities to reduce, prevent and control waste and pollution, and minimize their health-related impacts in small island developing states. It also set the target that by 2020 the use and production of chemicals in these states would not lead to significant adverse effects on human health and the environment (United Nations 2002).

The management of water resources on small islands is affected by complex and dynamic interactions of actors with different demands and interests. Agricultural activity is often one of the main actors influencing a society's water resources and environmental integrity.

On Tongatapu, the main island of the Kingdom of Tonga, an increased export of squash (*Cucurbita maxima*) to Japan has led to an increased import of agrichemicals. Since the start of the squash industry in 1987, the export of squash has increased from less than 1 tonne, to about 15 tonnes: the importation of agrichemicals increased from 0.25 to 1.7 million T$ over the period 1999 – 2001. These agrichemicals include fertilizers, as well as pesticides. Here we just discuss our findings in relation to the use of nitrogen fertilizer.

There are community concerns about the pollution of groundwater and the connected lagoon (Figure 1) due to the increased agricultural intensity. These concerns led to the EU and NZAID sponsored project called 'CROPPRO' (www.croppro.alterra.nl). This project focuses on the sustainable development of agriculture in small resource-constrained Pacific islands.


**Figure 1. Tongatapu is a raised atoll with an internal lagoon (top left). The underlying freshwater lenses (bottom left), which are connected to the lagoon and the fringing reef, provide the potable water supply. Squash pumpkin production (top right) relies on the use of fertilizers, and pesticides (bottom right).**

Freshwater on these islands is present as lenses floating on denser salt water underneath. Our research sought to develop alternative production practices to avoid losses of agrichemicals from the rootzone to the fresh-water lenses.

Water Flux Meters

In this tropical environment, robust and easily operated tools are needed to quantify the drainage of water and solutes towards the freshwater lenses. To evaluate the leaching of agrichemicals on Tongatapu, we used three types of newly developed water flux meters (WFM), four suction types (Gee *et al*. 2003), and two non-suction models. Here we report our results for drainage and nitrogen leaching using the non-suction WFMs.

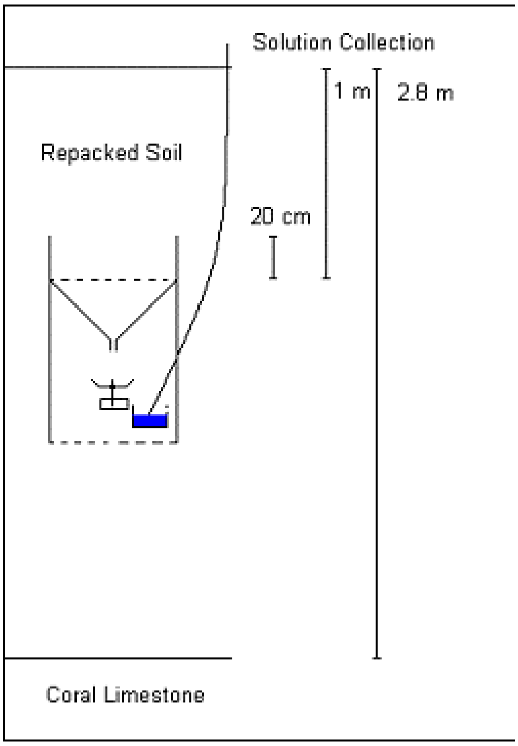


**Figure 2. The buried flux meter showing the tipping-bucket flow-recording device, and the reservoir from which solution can be collected using a syringe (upper right).**

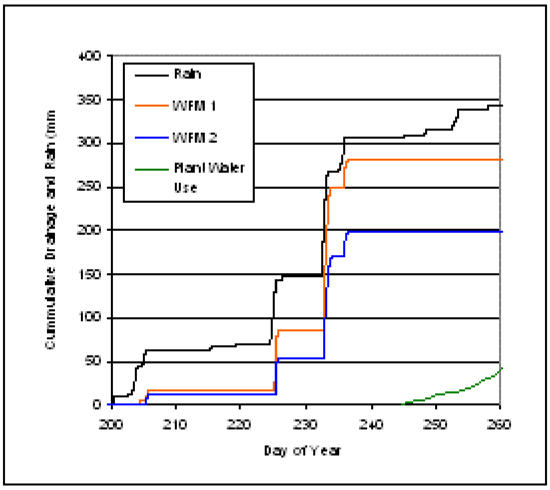

**Figure 3. The flux meter about to be buried in a pit where it can record drainage and allow sampling of the leachate.**

The WFMs were installed in an agricultural field cropped with squash during the 2002 (van der Velde *et al*. 2003), and 2003 (Figure 3) growing seasons. The soil is a heavy, structured clay derived from volcanic ash. The grass was ploughed in during June, and several diskings of the field ensured a good seed-bed. Total soil depth is about 2.8 m, after which there is, to depth, a permeable coral limestone base. The freshwater at this site occurs at a depth of 23 m. In contrast to the 2002 season, the WFMs in 2003 had a 200 mm ring on top to minimize flow divergence (Figure 2). The soil above the WFMs was repacked to ensure good contact with the collector. The structure of the repacked soil above the WFMs was similar to that of the ploughed and disked field. The WFMs were connected to a Campbell CR10X datalogger for continuous measurement of the drainage. Also connected to the logger were two Campbell Scientific CS615 soil moisture probes. The leachate from the WFMs was sampled manually after drainage had occurred. Cumulative rain, drainage and plant water use is shown in Figure 4 and the drainage flux and soil moisture changes in Figure 5.

**Results and Discussion**

During the growing season of 2002, our WFMs only measured, in total, some 16% of the cumulative rain. Then, there was no confining ring above the WFM. The data now presented for 2003 shows a capture of drainage that accounts for 58 to 82 % of the cumulative rain. This demonstrates the effectiveness of the flow-confining rings above the WFMs for ensuring representative sampling of the drainage.

During the period between DOY 220 and 260, there were three large rainfall events (Figure 5). Large volumes of drainage were recorded after these rains. Saturated flow, as measured by these non-suction WFMs, accounts for a large fraction of the deep drainage under these tropical conditions (Figure 4). As the crop cover developed beyond DOY 240, only then did transpiration increase. After full leaf-cover developed, and transpiration became higher, no further saturated drainage was measured by these WFMs. In Figure 4 is shown the modeled water use by the squash pumpkins. The modeled transpiration was corroborated using measurements of plant-water use. The transpiration was measured using heat-pulse equipment to monitor sap flow in the stems of the plants (Figure 6).



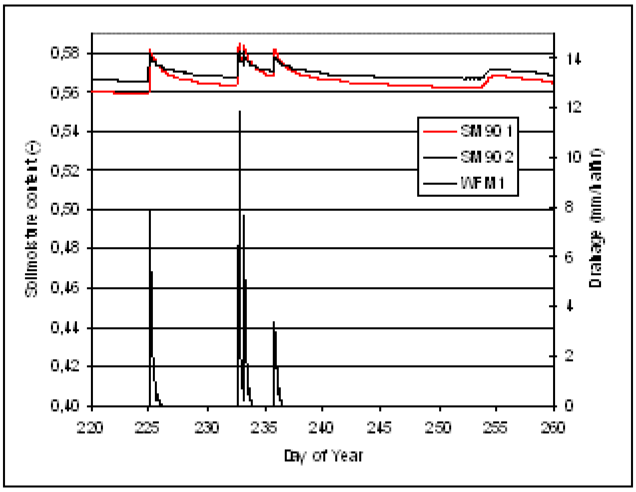




**Figure 4. Cumulative drainage and rain** **Figure 5. Drainage flux & soil moisture at 900 mm**

**Here WFM 1 and WFM 2 refer to the two flux meters, and SM 90 1 and SM 90 2 are the two Campbell soil moisture probes. Both measured rain and modeled transpiration are shown along with drainage in Figure 4.**

**Figure 6. The water-use of the squash pumpkin was measured using heat-pulse monitoring of the sap flow in the stems of the plant. The white wires in the stem on the right of the photo are connected to a heater needle (centre), and two temperature sensors either side.**

The standard fertilizer practice is that the soil of the mounds (1.5 x 1.5 m) receives an application of 120 g

NPK-S fertiliser (62 kg of N/ha) fertilizer at planting. In 2003, the NPK-S was applied to the mounds on DOY 204. Planting took place on the 25th of July (DOY 207). The drainage water collected from the WFMs was analyzed for $NO_3$-N (Figure 7) and $NH_4$-N. From Figure 4 it can be seen that a significant amount of drainage (Figure 5) and leaching (Figure 7) can occur before the leaf-area of the plants had grown to any extent. Given the low levels of plant water use, the majority of the rainfall is lost as drainage, and it carries with it a lot of nitrogen.

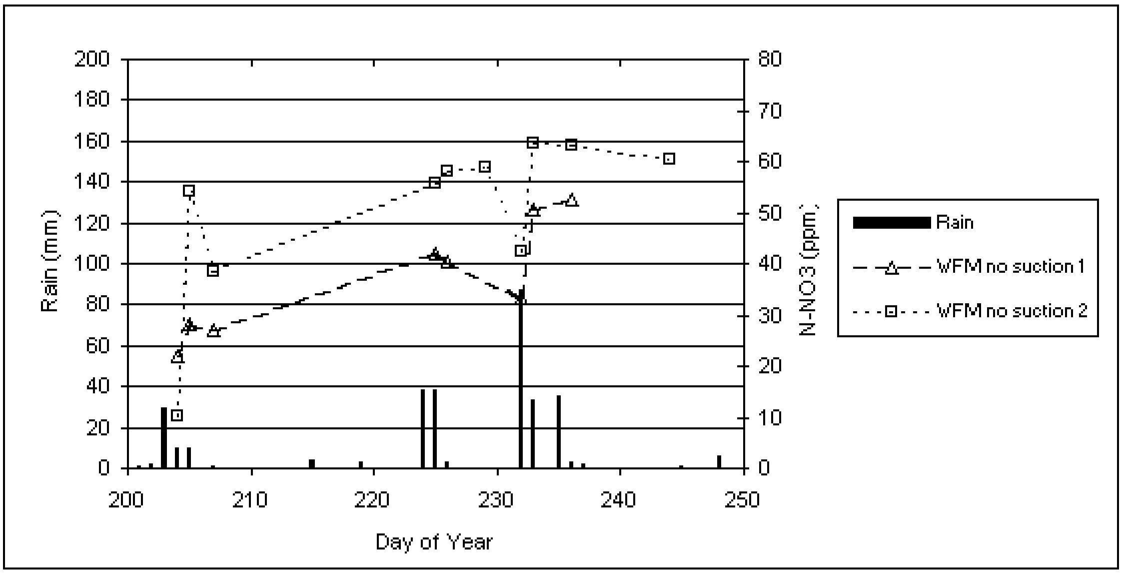



**Figure 7. The measured concentration of N-$NO_3$ (ppm) in the drainage water of the WFMs.**

Both WFMs record elevated levels of $NO_3$-N., and the first peak in $NO_3$-N can be observed in the leachate shortly after the N fertilization on DOY 204. There appears to be a gradual rise in the level of $NO_3$-N as further rainfall seems effective at leaching the applied N from the soil. The concentration in the drainage is well above WHO drinking water standards of 11.3 ppm $NO_3$-N for drinking water. The total amount of N lost over this period is about 125 kg-N/ha, which is nearly twice that applied as fertilizer. It would seem that the remainder has been supplied by N mineralized from the composting of the ploughed-in grass. Irrespective, it is clear that the N from the initial fertilization has been lost. Between DOY 200 and 250, the majority of the 350 mm of rain was lost as drainage because plant transpiration was insignificant as the plants had yet to develop a full canopy. Because the root system would not have been extensive, the plants would be incapable of taking up either water, or nitrogen.

The initial application of N would not only seem wasteful, but also prejudicial to the quality of the receiving waters.

**Conclusion**

A mix of social, economic and environmental factors drives conjunctive management of Tongatapu's agricultural practices and water resources. It is important that economically sustainable squash-production practices are developed, and that these protect the island's susceptible water resources and fragile environment

Our measurements and modeling of the water balance and nitrate fluxes is a first step in an integrated effort to find balanced solutions to develop economic production systems for squash farmers, and to ensure that these protect Tongatapu's freshwater resources and aquatic environments. Our next step will be to prescribe sustainable pesticide practices that are effective for disease control, yet do not result in the leaching of the active ingredients to groundwater.

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**Appendix 3: CROPPRO Sustainable agriculture in a clean environment**
**Report on Meeting 1st – 2nd July, University of the South Pacific, Alafua, Samoa.**

Brett Robinson, HortResearch, Private Bag 11 030, Palmerston North, New Zealand.

**Present:**

Jannes Stolte, Erik van den Elsen (Alterra)
Walter Vermeulen, David Hunter + Others (USP, Samoa)
Wilco Liebregts (EcoConsult, Fiji)
Maria Elder, Joseph Veramu + Others (FCEA/USP, Fiji)
Viliami Manu, Vuni Menoniti (MAF, Tonga)
Brett Robinson (HortResearch, New Zealand)

**Background**

The European Union-sponsored CROPPRO project aims to provide assistance to Pacific Island countries by the development of integrated farming approaches for sustainable crop production in environmentally constrained systems. The project specifically addresses the relationship between agricultural activities and the surrounding environment, and focuses on the development of tailor-made farming approaches for major crop/soil units aimed at maximising agricultural production, and minimising environmental deterioration with its social and health implications. Special attention is paid to knowledge transfer and participatory, culture-sensitive training for stakeholders and end-users. These aims will be met through related, but independent, research projects in Fiji, Tonga, and Samoa in collaboration with local researchers, landowners and users, and government and non-government bodies. While the majority of the CROPPRO project is funded by the European Union, HortResearch's involvement is supported by NZAID.

The project commenced in November 2001 and is due to conclude November 2003.

*Meeting objectives*

The objective of the meeting on the 1st and 2nd of July was for all CROPPRO partners to give progress reports, address and progress issues and determine the methods by which the programme will be concluded. This latter objective included means by which information gained in the programme would be disseminated, and a possible six-month extension of the project.

**Overview of progress**

*Tongatapu*

The CROPPRO goals on Tongatapu were to optimise agricultural production while protecting groundwater and soil quality. This will be achieved by constructing guidelines for the fertiliser and pesticide application. In particular, the type and amount of agrichemical used as well as the timing of application are critical for sustainable production.

HortResearch has completed all field measurements for this project and is processing the data obtained to provide recommendations for the aforementioned pesticide and fertiliser practices.

Thus far, the results indicate that current fertiliser use practices have resulted in an increase in the concentration of nitrogen and phosphorous in Tongatapu's groundwater lens. Furthermore, soil measurements infer that the use of inappropriate fertilisers and pesticides is placing a heavy-metal burden on some agricultural soils.

Our results have also shown, that changes in the timing and rates of fertiliser application would not only reduce contaminant leaching, but also improve the growth response of squash, the principal crop on Tongatapu.

HortResearch scientists will make a final visit to Tonga at the end of October to produce and distribute environmental tools that can be use by both farmers and regulators to implement the best management practices for sustainable agriculture.

HortResearch's progress report No. 5 contains a full account of our scientific findings to date.

*Fiji and Samoa*

Unlike Tongatapu, the CROPPRO goals in Fiji and Samoa focused on sustainable production while preventing soil erosion, which can be an issue on these mountainous islands. This will be achieved by using an erosion model, LISEM, to calculate the erosion under various cropping regimes. The results of the LISEM calculations will be used to draw guidelines for the best agricultural practices depending on the environment of the land being farmed.

In Fiji, much of the data to run LISEM has already been obtained, although more will need to be collected before definitive erosion calculations can been made. In Samoa, the vandalism and theft of equipment has delayed data collection.

LISEM calculations made using these preliminary measurements augmented with synthetic data have been done to produce a ranking of the relative impacts of various cropping practices on erosion.

*Project reporting and technology transfer*

After outlining the scientific progress of the CROPPRO programme for Tonga, Fiji and Samoa, the meeting discussed socio-economic aspects of implementing the Best Management Practices that have been derived from the scientific data.

Management guidelines will be implemented using a Participatory Rural Appraisal (PRA). PRA aims to solve measurable problems using knowledge that is co-generated by all stakeholders. Social action is seen as important in changing attitudes. The effects of PRA are measured scientifically, such as crop production volumes or environmental quality. PRA follows a prescribed course of:

(1) Get to know the target community
(2) Find out about any problems
(3) Set objectives and targets
(4) Prepare an action plan
(5) Implement plan and monitor progress
(6) Evaluate the plan and make changes as needed.

It was agreed that the results of CROPPRO could be disseminated as booklets leaflets, and computer-based Decision Support Tools, which would be translated into the local tongue. In all three countries, regulators as well as some farmers have computer access via the local university or agricultural ministry.

There will be a duel approach to publishing, with both popular and scientific articles prepared. One possibility is to produce a book of conference proceedings on the outcomes of CROPPRO.

Finally, the participants discussed the possibility of extending the programme by six-months, to allow time for further data collection in Fiji and Samoa. HortResearch restated its intention to finish its programme goals by November 2004.

**Appendix 4: Abstract of paper submitted to an international conference on** *Integrated Assessment of Water Resources and Global Change: A North-South Analysis,* **Bonn, Germany, 23-25 February 2005.**

Sustainable development and small island developing states: protecting freshwater resources from agricultural intensification on the coral atoll of Tongatapu

M. van der Velde[1], M. Vanclooster[1], S.R. Green[2] and B.E. Clothier[2]

Abstract
Tongatapu (175°12'W, 21°08'S) a coral atoll located in the Pacific Ocean and the main island of the Kingdom of Tonga. The size of small island developing states (SIDS), like Tonga, in an socio-economic and biophysical sense makes them extremely vulnerable to fluctuations on the global market and environmental disasters like cyclones. They are also likely to be one of the first to be confronted with rising sea levels which poses a threat to their water resources. Currently there are already several pressures on the freshwater resources which include waste and sewage disposal, construction works along the coast, and the impacts of intensifying agriculture. On Tongatapu (256 $km^2$) agricultural practices have intensified since 1987 when a niche period for the export of squash into the lucrative Japanese market was identified. Over the last 10 years the export of squash has accounted for about 40% of the GDP of Tonga. With the increase in export a manifold increase in the importation and usage of agri-chemicals has occurred. This has led to increasing concerns and mounting evidence of pollution of the freshwater lenses that float underneath the island. We are currently involved in an integrated project (www.croppro.alterra.nl) involving local stakeholders, Ministry of Agriculture officials and scientists that is aiming to develop more sustainable agricultural practises in constrained island systems in the Pacific region. Here we present the case study of Tonga to illustrate the specific problems encountered in the domain of sustainable development in SIDS and the use of a decision support tool, which allows farmers to select the most "sustainable" pesticides for their agricultural practices in terms of long and short term leaching risks towards the islands freshwater lenses.

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**Appendix 5: Abstract of a paper submitted to *Agricultural and Forest Meteorology***

Transpiration of squash under a tropical maritime climate

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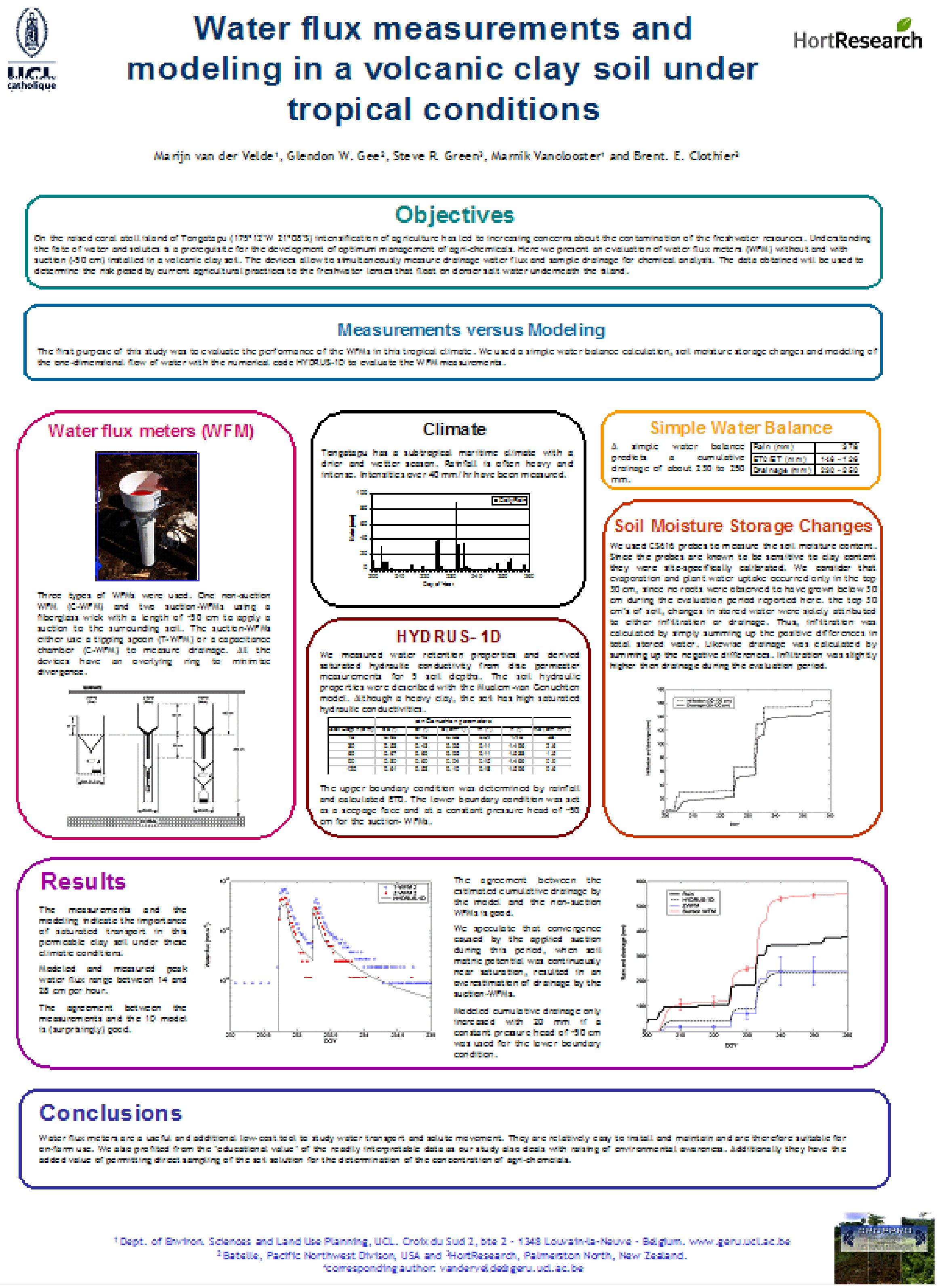
*Keywords:* Sap flow, transpiration, big-leaf model, Cucurbita, water-stress, crop factor

Abstract
We present the measurement and modelling of transpiration from squash (*Cucurbita maxima* Duchesne) growing in the field under a tropical maritime climate. Measurements were carried out on Tongatapu (175°12'W, 21°08'S), a coral atoll located in the Pacific Ocean. Transpiration was determined from heat-pulse measurements of sap flow in the vine stem using the T-max method. Steady-state porometry was used to monitor leaf stomatal conductance ($g_s$, mm $s^{-1}$). The data were used to derive parameters for a functional model of conductance that includes response functions for light, air temperature and vapor pressure deficit of the air, and a novel response function for soil moisture. Leaf area development was monitored through the growing season using a point quadrat approach. The maximum leaf area was about 2.7 $m^2$ per plant and the effective ground area was about 1 $m^2$ for each plant. Transpiration losses were calculated using a 2-layer big-leaf model in combination with modelled stomatal response and measured leaf area. In general, the sap flow measurements were in good agreement with the calculations of plant water use. Peak water use was between 3 to 5 L per plant per day. Daily transpiration measurements from heat-pulse were used to derive a crop factor, $K_C$, for squash in this tropical maritime climate. The derived seasonal pattern of $K_C$ was similar to the FAO recommended crop factor for squash. However, the growing season was a little shorter. Measured sap flow also revealed periods of short-term drought and leaf fungal disease that reduced the actual transpiration losses, and there was often a rapid recovery from water stress following rainfall events.

**Appendix 6 Poster presented at EuroSoil 2004 in Freiburg, Germany, 4-12 September, 2004**



**Appendix 7 Poster presented at EuroSoil 2004, Freiburg, Germany 4-12 September, 2004**

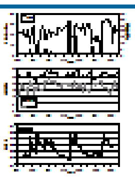
# Measuring and modeling plant transpiration under tropical conditions

Marijn van der Velde[1], Steve R. Green[2], Marnik Vanclooster[1] and Brent. E. Clothier[2]

## Objectives

Cucurbita maxima (Squash) is the main agricultural export product of the Kingdom of Tonga. It has accounted for about 40% of GDP for the last 10 years. The use of agri-chemicals for the cultivation of squash has led to concerns of the contamination of Tongatapu's water resources. We use a field water balance to assess the risk to the environment posed by the current agricultural practices. Transpiration is a key component of the soil-plant water balance. To quantify transpiration we used the heat pulse technique in squash (a non-woody herbaceous species) to measure sap flow. The results of the heat pulse technique were compared to a Penman-Monteith type equation with measured sunny and shady leaf area. A semi-empirical model was used where leaf stomatal conductance responds to air temperature, vapour pressure deficit, solar radiation and that incorporates a novel approach to account for the soil's moisture status.

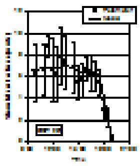
## Climate and Experimental Site



The experiments were carried out on the island of Tongatapu (175°12'W 21°08'S), a raised coral atoll and the main island of the Kingdom of Tonga, located in the South Pacific Ocean. Measurement were carried out over a 60 day period in the dryer season of Tongatapu's climate. ETO was typical for a humid subtropical climate. The air temperature ranged between 10° to 30°C. There were several rainfall showers during the period. After the rain, water in the root zone was gradually depleted by the plants.

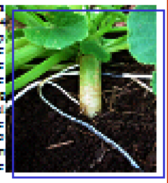
## Stomatal Conductance Model

Steady state porometry was used to measure the stomatal conductance of the squash. Squash plants control evaporative losses by closing stomata in response to elevated VPD as well as decreasing light levels and a decline in soil water availability. The empirical modelling approach of Winkel and Rambal (1990) was used to model the stomatal response.



A diurnal trace of stomatal conductance of squash leaves for DOY 281. The symbols represent the mean of six sunlit leaves with standard error bars around the mean. The line is the modelled stomatal conductance.

## Heat Pulse Technique



Miniature heat pulse sensors installed in the stem of a 4 week old squash plant. Sap flows from the soil through the stem and is lost to the atmosphere via stomata on the leaf surface. Here we are using the T-max method. A central heater probe is used to induce a 0.5 second pulse of heat into the stem. A single downstream sensor is used to monitor the time ($t_M$) for a peak temperature rise to occur at a distance ($x_D$) of 1 cm from the heater. A second temperature sensor is placed at a distance of 3 cm upstream from the heater to record any background changes in stem temperature not associated with the heat pulse. The theoretical calibration procedure of Green et al. (2003) is used to convert measured heat pulse velocity (v) to a sapflow rate

$$v = \sqrt{x_D^2 - 4\kappa t_M} / t_M$$

$$\kappa = x_D^2 / 4t_M$$

The thermal diffusivity κ ($m^2 s^{-1}$) of the of the sapwood matrix is practically determined where $t_M$ (s) is measured during the night. At this time it is assumed that no convective heat transport takes place as sap flow becomes very low or ceases.

## Penman-Monteith

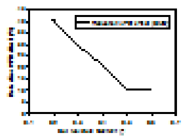
The evaporation of the plants is modelled as a sum of hypostomatous leaves exposed to air with a common ambient saturation with a certain fraction of the leaves exposed to full sunlight and the other fraction of the leaves in the shade.

## Water Stress Function

Using our original stomatal conductance model we observed a overestimation of transpiration compared to measured transpiration on days with a high VPD and low available soil moisture. To account for the water stress experienced by the plants we used a functional approach that reduces the effect of vapour pressure deficit at low soil moisture contents.

$$K_s = 1 - (\theta - \theta_{min}) / (\theta_f - \theta_{min})$$

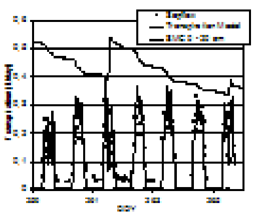
Hereby we suggest that the plants actively close their stomata in response to low soil water availability



## Results

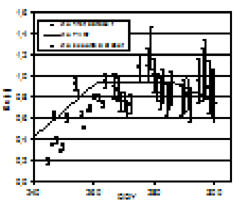
Measured and modeled transpiration rate are in close agreement. The water uptake of the plants is also reflected in the decrease of soil moisture measured near the main plant root.

Daily water use increased in the beginning of the season from 0.5 L per plant to 2.5 L per plant.




Using the FAO reference crop evaporation we were able to derive a crop factor for squash under tropical conditions from the measurements.

The derived crop factor corresponds with the crop factor provided by FAO for a mediterranean climate. The length of the growing season appears to be slightly shorter in this climate.




## Conclusions

The dualistic measuring and modelling approach enabled us to understand transpiration of squash in the field under tropical conditions. We used an equation to account for water stress experienced by the plants during days with a high vapour pressure deficit and low soil moisture availability which improved our model predictions. The agreement between the measurements and the model adds to our confidence that heat pulse can be used in non-woody herbaceous species.

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