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# Sustainable and profitable crop and livestock systems in south-central coastal Vietnam

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# **Sustainable and profitable crop and livestock systems in south-central coastal Vietnam**

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*Editors:* Surender Mann, Mary C. Webb and Richard W. Bell



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Cover: Smallholder crop and livestock management systems and their implications in south-central coastal Vietnam. (Photo: Richard W. Bell)

# Opportunities and priorities for further investment in improving the productivity and sustainability of crop and livestock systems on sands in south-central coastal Vietnam

Richard W. Bell<sup>1</sup>, Hoang Minh Tam<sup>2</sup>, Robert Summers<sup>3</sup>,  
David Parsons<sup>4</sup> and Allan McKay<sup>3</sup>

## *Abstract*

The South-central coastal (SCC) region of Vietnam has challenging constraints to productive and sustainable intensification of agriculture: low fertility sandy soils, long dry seasons and shallow groundwater. The present proceedings describe studies in three provinces (Binh Dinh, Phu Yen and Ninh Thuan) representing a range of climates, farming systems and sandy landscapes of SCC Vietnam. The chapters in these proceedings analysed the value chains for key agricultural commodities, characterised the constraints on the sands, demonstrated the productivity gains from balanced nutrient inputs, soil amendments and better irrigation scheduling and showed improved profitability of beef-cattle management through better quality forages and programs to improve on-farm practices. Many interventions for improved market access and profitability of cropping and beef-cattle enterprises have been identified and partially tested. More details of these findings are outlined below and in the preceding chapters. Identification and alleviation of soil constraints are highlighted as a key priority for productive cropping in this region. Integration of cropping with profitable livestock production is a notable opportunity for the intensification of farming systems. Sustainability of groundwater resources is a significant issue for the future of agriculture in the SCC region of Vietnam.

## Introduction

Development of profitable and sustainable crop and livestock production systems in challenging environments (poor, sandy soils under water-limiting conditions) of south-central coastal (SCC) Vietnam has progressed from Australia–Vietnam research

collaboration. The baseline conditions of farming systems studied in Binh Dinh, Phu Yen and Ninh Thuan provinces indicate both similarities and significant differences across SCC Vietnam (Hoang Thi Thai Hoa et al. 2015a, c). The research described in these proceedings was designed as a multidisciplinary venture linked with national research institutes, including provincially based research and extension departments (Mann et al. 2015). Its aim was to identify and facilitate adoption of promising resource management practices for sustainable and profitable crop and livestock production systems best suited to local conditions that enabled improved market engagement. The papers in these proceedings analysed the value chains for key agricultural commodities, characterised the constraints on the sands

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<sup>1</sup> School of Veterinary and Life Sciences, Murdoch University, Murdoch, Western Australia

<sup>2</sup> Agricultural Science Institute of South-central of Vietnam, Quy Nhon, Vietnam

<sup>3</sup> Department of Agriculture and Food, Western Australia, Waroona, Western Australia

<sup>4</sup> University of Tasmania, Sandy Bay, Tasmania, Australia  
Email: r.bell@murdoch.edu.au

of SCC Vietnam, demonstrated the productivity gains from balanced nutrient inputs, soil amendments and better irrigation scheduling, and showed improved profitability of beef-cattle management through better quality forages and programs to improve on-farm practices. Many interventions for improved market access and profitability of cropping and beef-cattle enterprises have been identified and partially tested. Key findings are outlined below. Opportunities and priorities identified are discussed and then the relevance of the findings to the wide coastal zone of central Vietnam is analysed. The identification and alleviation of soil constraints is highlighted as a key priority for productive cropping. The intensification of farming systems by integration of cropping with profitable livestock production is a notable opportunity. Sustainability of groundwater resources was identified as a significant challenge for the future of agriculture in the SCC region of Vietnam.

## **Value-chain analysis of the major commodities**

Value-chain analysis of key agricultural products (peanut, cashew, mango, beef cattle, cassava, sesame and garlic) reveals a wide range of potential chain improvements that would benefit farmers in the SCC region. There are clear opportunities to boost productivity and profitability within the prevalent low-input farming systems. Simple and cost-effective interventions in areas such as postharvest technology and marketplace improvements can have an immediate effect. Many of these interventions are the subject of soil fertility, crop and animal nutrition and irrigation research reported within these proceedings. Progress has been made on understanding and facilitating improvements in a range of product quality related issues.

### **Peanut**

Farming systems incorporating peanuts are well suited to intensive cultivation on poor sands, particularly in Binh Dinh province. These farming systems help poverty reduction and soil improvement (Phan Thi Giac Tam and McKay 2015). However, the development of these farming systems has resulted in the depletion of groundwater in the dry season, due to overexploitation and possibly exacerbated by climate variability. Recognising the severity of water depletion, farmers have begun to apply water-saving measures, such as sprinklers, while biochar made from rice

straw is another input with potential for increased water use efficiency. While these interventions are gaining popularity, there is a growing need for extension support to maximise the benefit of groundwater use while reducing impacts of its overuse.

To overcome the increasing effects of storms due to climate variability, Binh Dinh authorities have supported autumn–winter peanut cropping to replace cassava in the rainy season. This peanut crop, despite low productivity due to postharvest damage, is still economically viable for farmers because of high prices. The postharvest and seed storage problems for the autumn–winter peanut crop are potentially solved by the introduction of grain dryers (Phan Thi Giac Tam and McKay 2015).

### **Cashew**

Cashew trees are adapted to soil and climatic conditions in other areas of Vietnam and cashews generate high export revenue so that it is important that a clear cashew industry development strategy is pursued. While cashew yields and profitability can be improved, especially in Binh Dinh province, it is concluded that cashew in Phu Yen and Ninh Thuan provinces is not capable of improving the livelihood of farm households. There are many unproductive orchards where yields are low due to a low-input production approach. Constraints in cashew production include lack of improved varieties, poor site selection and lack of good grafted trees for planting. Yields can be increased by adoption of more intensive production methods in plantations of suitable grafted varieties. Balanced crop nutrition including micronutrients in conjunction with incorporation of biochar has been shown to boost yields. Domestic cashew nut supply is inadequate to fulfil the requirements of processors. The cashew-processing industry is potentially a major source of jobs for the population of the SCC region. Phu Yen and Ninh Thuan cannot supply enough raw cashews to meet processor demand and processors are dependent on importing raw cashews. Cashew plantations are significant in agricultural production in SCC Vietnam although many policies and technical problems need to be solved for higher productivity (Nguyen Duy Duc and Pham Nhat Hanh 2015).

### **Mango**

A significant market opportunity currently exists for mango producers in SCC Vietnam because their main harvest season is later than the main season



in the Mekong River Delta region. However, it is important to note that increasing 'off-season' production of mangoes from the Mekong River Delta is occurring via the use of growth regulators to manipulate flowering time and this has the potential to compete with SCC production. To capture mango market opportunities, SCC mango quality, varieties and postharvest handling will need to be improved. Opportunities also exist to boost yield and profitability of mango by improved crop nutrition and water use efficiency (Hoang Vinh et al. 2015a, b; Hoang Minh Tam et al. 2015). Mango production in the three focus communes (Cat Trinh in Binh Dinh province, An Chan in Phu Yen province and Phuoc Dinh in Ninh Thuan province) was on a small scale with low investment and productivity. The number of fruit traders was low and linkages among mango growers, collectors, wholesalers and retailers was limited. Growers receive a high proportion of the profit in the mango value chain; however, lack of capital investment often limits inputs such as fertilisers. Mango production in SCC Vietnam is a fledgling industry and requires coordination and collaboration to reach its potential (Luong Ngoc Trung Lap and Nguyen Minh Chau 2015).

### **Beef cattle**

Cattle husbandry makes an important contribution to income, cash flow and financial stability of farm households in the SCC region of Vietnam (Ho Cao Viet et al. 2015a). Prices of live cattle and beef meat have tended to move upwards over time, and demand for beef is strong in the south and city markets. Farmers' attitudes to cattle production are changing rapidly, with more focus on intensive management and breed improvement. Government policies and private enterprises can improve both quality and quantity of cattle herds in the three provinces by supporting the establishment of slaughter facilities, veterinary services, programs of artificial insemination, and expanded pasture and forage production. Cattle manure is an important source of nutrients for cropping land (Hoang Vinh et al. 2015a; Hoang Thi Thai Hoa 2015b).

Benchmarking studies of beef-cattle production suggest that practices vary greatly. Substantial improvements can be achieved through improved management, particularly better feed management. Participatory research has been very successful in livestock and fodder species work, resulting in

substantial uptake of practices as a direct result of trials and workshops (Ho Le Phi Khanh et al. 2015). Improved management practices, including more intensive cultivation of forages, can lead to substantial labour savings. Demonstration and pilot studies are an important and necessary requirement for widespread adoption of practices by regional authorities and extension staff. Inclusion of exchange staff into the program has had very positive impacts on research understanding and communications (Ho Le Phi Khanh et al. 2015).

### **Cassava**

In recent years, high variation in the cassava price influenced farmer incomes and willingness to continue growing cassava. Reduced selling prices (by 20% at the farm gate) combined with increasing input costs decreased cassava profits in 2011 by about 30% compared with 2010. However, several promising options were identified to improve the profit from cassava and decrease price volatility. Firstly, small-scale cassava-processing units (sticky and dried starch processing) generate more stable income and help mitigate risks of falling prices. The storage of cassava roots by traditional methods and use as a feed for fattening the cattle or as a source of modified feed in the dry season is a high-efficiency option for farmer households in the context of falling fresh root prices. Income from cattle feed on cassava by-products is a source of capital for cassava cultivation and vice versa in the farming system. Cassava products and by-products are important feed sources for cattle, especially during the dry season. Cattle production enables greater flexibility in cassava production where the farmer has the option of selling to processors or retaining for animal feed depending upon the returns. Production of cassava chips is also highly efficient and profitable but requires good weather, can be on only a small scale and needs high labour input. Starch-processing factories still play an important role in the cassava value chain, but dependence on the Chinese market is risky (Ho Cao Viet et al. 2015b).

### **Sesame**

Sesame is a drought-tolerant short-season high-value crop suited to SCC Vietnam, although yields are generally low under rainfed conditions on sands. Sesame is a good fit in rotation with peanuts in this region. For sesame production, farmers often lack access to capital to increase scale and adopt improved

production technology. New varieties of sesame with higher yield and quality are a high priority for industry development. The biggest issue for sesame collectors is lack of access to capital. Traders also lack capital and bank loans are difficult to source, so private loans with high interest rates are common. Equipment to measure moisture content of sesame seeds and suitable transportation are needed by sesame collectors. Assessment of market demand is difficult because there are few close links between sellers and consumers. Although the collectors play an important role, there is no policy or system supporting the delivery to farmers of market price information. For sesame, the long value chain and loose linkages do not encourage a focus on quality control along the chain. Without support, farmers are expected to continue to prefer crops such as cassava rather than face the risks with sesame (Nguyen Thanh Phuong and Nguyen Van Duong 2015).

### **Garlic**

The small-size garlic produced in Ninh Thuan province has a reputation for superior flavour in Vietnam. It is a relatively minor crop but important in that it is one of only a few crops that can be profitably produced on sands in Ninh Thuan. Together with onions, garlic has contributed significantly to household income but the sector in the province appears to be declining in area and production. Yield has been unstable in recent years because of a combination of unfavourable weather and poor farming practices. Demand from both domestic and foreign markets remains strong with unmet demand. However, the relatively small production scale causes some disadvantages in terms of price forecasting and setting.

Garlic production has high levels of inputs and associated high production costs. These are associated with overuse of pesticides and incomplete fertiliser application. While growers in Ninh Thuan have long had experience with growing garlic they appear to lack technical knowledge and skills to cope with emerging conditions such as climate extremes and disease incursion, resulting in low yields, poor quality and reducing growers' profits.

Due to its long association with garlic, Ninh Thuan province had a strong and experienced collector force, traders and a network that links from local production to market. The fact that there are presently individuals and traders who are pioneering and promoting safe production and safe products to

market is considered to be a strength as their interest lies in exporting good-quality, residue-free products to other countries to get higher value. The value distribution within the chain seemed fair except for the deduction ratio (arbitrary quality classification of garlic bulbs assessed by the collectors, averaging 5%) that has long been applied to growers, lowering the profit margin of the farmers from 32.5% to 27.5%. Wholesalers normally apply only a 1% deduction ratio to collectors, shifting 4% profit margin in their favour that could have gone to the producers (Nguyen Van Bang and McKay 2015).

### **Soil properties: nutrient and soil water constraints**

Sands occupy over 0.5 million hectares (ha) in Vietnam, with over two-thirds of that area in SCC Vietnam (Bell et al. 2015). There is a range of constraints that limit agricultural productivity on the SCC sands. The present studies determined the range of sand profile types in the SCC region, their origin and distribution, and key limiting properties (Bell et al. 2015). Study areas were located in Phu Cat district of Binh Dinh province, Tuy An district of Phu Yen province and Thuan Nam district of Ninh Thuan province to capture the main variation in types of sands and climatic influence on land use.

### **Soil properties and constraints**

The sands were diverse in clay content, soil colour, pH and texture, which varied with depth. Most of these differences can be attributed to parent material which comprised aeolian sands (from white and red dunes), alluvial terraces, marine sediments, colluvial sediments (mostly from granite) and in situ weathered granite, with or without surface reworking of sands by aeolian, fluvial or slope processes. Most of the sands were acid, but even when strongly acid contained little extractable aluminium. Alkaline sands in restricted areas were also identified in Ninh Thuan and Phu Yen provinces. Organic carbon, cation exchange capacity (CEC) and water retention at  $-0.1$  bars were generally very low but clearly increased with clay content that varied from zero to almost 20%. Management influences on sand properties were also evident. On acid sand that have been used for crop and vegetable production, there was evidence of phosphorus leaching down profiles. Peanut fields in Binh Dinh often had elevated, even moderately

alkaline, near-surface pH attributed to repeated lime applications. In Binh Dinh, there was some evidence of compaction of sands in the rooting zone for crops.

In addition to the constraints identified in the Soil Constraints and Management Package (SCAMP) assessment of 56 profiles, a diverse range of nutrient disorders were diagnosed in sands in Phu Cat district (Binh Dinh province) and Ninh Phuoc and Thuan Nam districts (Ninh Thuan province) (Hoang Minh Tam et al. 2015). On most of the sands, multiple deficiencies were identified. While potassium and sulfur were deficient on all sands tested, the suite of deficient micronutrient deficiencies varied among types of sands. Hence, it is concluded that nutrient deficiencies need to be systematically diagnosed in SCC Vietnam in order to develop productive and profitable cropping systems after correction of these deficiencies.

Irrigation is essential for crop production in the dry season in SCC Vietnam. Use of a mini evaporation pan to guide irrigation frequency and the amount of water applied increased peanut yield in Phu Cat district on sands compared with the farmers' irrigation practice. The yield increase varied from 0.23 to 0.50 t/ha in 3 years, 2010–12. Importantly, the number of irrigation events required decreased by 50% with substantial labour savings from the use of the mini pan to schedule irrigation (Hoang Vinh et al. 2015b). The results suggest that substantial improvements in water use efficiency can be gained by better irrigation techniques (mini pan) for peanut. However, further experiments to validate these findings across a wider range of sites on farmers' fields are needed, together with a program to demonstrate profitability on a larger field scale. In addition, more efficient water delivery and labour savings are likely with alternatives to the current practice of watering by hand-held hoses.

### **Water resources**

Water resources have been identified as being under threat through a combination of over-utilisation (Keen and Chu Thai Hoanh 2015; Phan Thi Giac Tam and McKay 2015), drought or climate change, and contamination (Do Thi Thanh Truc et al. 2015) in the study area. The present findings suggest that irrigation efficiency can be greatly improved in some crops at least, but that more systematic evaluation of the best technologies for farmers in SCC Vietnam is urgently needed.

In summary, there appear to be multiple nutrient deficiencies in many of the crops studied, and opportunities for considerable savings in water through improved irrigation practices on sands of SCC Vietnam. Hence, significant productivity, profitability and sustainability gains are possible through integrated nutrient, soil and water management in this region. However, systematic programs of research are needed to design packages of practices suitable for farmers in SCC Vietnam. These need to be supplemented by programs to test recommendations and investigate further options for adoption by farmers. Better management of organic by-products in the farm system (e.g. manure, biochar, crop residues) and inclusion of livestock in the on-farm studies should be integral to such investigations (Hoang Vinh et al. 2015a). The application of biochar to sands in Vietnam soils would appear to have potential given: its stability in soils relative to organic matter; the nutrient value of biochar; and comparative simplicity of its manufacture. However, there are competing uses of crop residues for livestock feedstock as opposed to biochar manufacture. To improve nutrient retention in sands of SCC Vietnam, biochars may need to be applied regularly over many years. To meet this demand, further development is required for home-based production technology of biochar from rice husk, a readily available feedstock, which has the added benefit of being able to produce gas for domestic cooking.

## **Opportunities and priorities**

A key output of the studies reported here was to identify promising interventions for value chains that would increase profitability and market access for producers in SCC Vietnam. Interventions in peanut, cashew, mango and beef-cattle value chains appear to have most promise of delivering widespread benefits to smallholder farmers in SCC Vietnam. We suggest that further support from the Government of Vietnam could be directed to help local authorities implement strategies recommended in these proceedings (Section 3). Continued monitoring of the impacts of these technical interventions is also required.

### **Peanut**

To increase the competitiveness of the peanut value chain in SCC Vietnam, better market facilities and upgraded mechanisation for harvesting, threshing, grading and drying are needed. Traders play a



very important role in the peanut value chain and policy support is needed in terms of access to credit and capacity building (i.e. training in postharvest technology, food safety, business management) and provision of world market information. Greater input to the technology transfer process is needed to lift farmer awareness and aid adoption. Significant profitability increases can be achieved through balanced nutrient supply, including potassium, sulfur and micronutrients, but fertiliser application packages that are profitable for farmers need to be designed and demonstrated in the region for farmer adoption. Opportunities and directions for development of nutrient management packages are discussed elsewhere (Bell et al. 2015; Hoang Minh Tam et al. 2015; Hoang Thi Thai Hoa et al. 2015b; Hoang Vinh et al. 2015a; Hall and Hoang Vinh 2015) and summarised below.

### **Cashew**

For cashew, careful consideration of the suitability and viability of this tree crop on sands in SCC Vietnam is needed. For areas identified as most promising for cashew, a selection program to identify large kernel, disease-tolerant varieties that are suited to local conditions was proposed in the value-chain study (Nguyen Duy Duc and Pham Nhat Hanh 2015). A strategy for the cashew nut industry (varieties, technology requirements, investment etc.) should be developed through collective decision-making processes that will take into account risks faced by each participant in the value chain. Improved crop management practices for nutrition, irrigation and disease control need to be widely extended to improve yields of existing plantations. These improvements in tree management for productivity need to be coupled to a strategy for the staged replacement of old trees in plantations by improved grafted varieties or replacement of cashew entirely with other farm enterprises in order to raise farmers' incomes in the SCC region.

### **Mango**

Mango from the SCC Vietnam arrive in the markets in major cities later than those from the Mekong River Delta, giving the SCC region a comparative advantage if the value chain and branding for mango fruit from SCC Vietnam can be developed (Luong Ngoc Trung Lap and Nguyen Minh Chau 2015). For mango in the SCC region, a comprehensive assessment of the market opportunities and potential market size needs to be undertaken so that rapid industry

expansion does not result in oversupply. Training and extension of improved cultural practices for farmers is required. Consideration should be given to establishing a mango cooperative, particularly if an improved, differentiated mango variety becomes available. Opportunities were identified for boosting yield of mango with application of potassium, sulfur and micronutrients at adequate rates (Hoang Minh Tam et al. 2015; Hoang Vinh et al. 2015a).

### **Beef cattle**

For cattle, it is recommended that support programs be strengthened, focusing on remote areas, where farmers face difficulties in accessing veterinary services and animal husbandry training (Ho Cao Viet et al. 2015a). Forage areas could be increased by introducing new grass varieties that are highly productive and drought tolerant to meet the feed demand of increasing numbers of cattle. A successful scale-out activity involving farmer-to-farmer learning of the technology for growing and utilising improved pastures is described in Ho Le Phi Khanh et al. (2015). Efforts should be made to commence a pilot program for cattle-raising households, and including the local middlemen, to organise a vertically coordinated chain for supplying higher quality beef to markets. Planning is needed to increase slaughter and processing capacity in the SCC region in order to supply beef meat and other processed products to large city markets. Training for farmers and extension staff on marketing is also needed.

### **Cassava**

For cassava, it is recommended that a plan be developed for processing factories in the region, focusing on cassava chip production (Ho Cao Viet et al. 2015b). Cassava-processing factories would diversify the market and avoid dependence on the Chinese starch market. There is a need to select and release high-starch (>30%) short-season cassava varieties that are well adapted to lowland conditions. Scaling up and establishment of small-scale cassava-processing units by groups of farmers could be considered for improving market options and returns from cassava. However, such a strategy would require a change in government policy after assessing the risks of environmental pollution from the disposal of processing waste and the best means of coordination of small processing units and whether they can maintain product quality. Wider adoption of the method of traditional storage of roots in the rainy season, combined

with its use as a modified feed source for fattening cattle in the dry season, would further buffer cassava production against price fluctuations.

### **Sesame**

For sesame, a better understanding of the yield potential of improved genotypes that meet high-value end uses is needed under both rainfed and irrigated production systems on sands in SCC Vietnam. This could be conducted in conjunction with rotation studies with other annual crops, such as peanuts and cassava, and should include crop nutrition and soil amendment studies. There is a need to provide improved and timely market and price information to sesame growers (Nguyen Thanh Phuong and Nguyen Van Duong 2015). Publication and extension of research findings for sesame in the SCC region would act as an aid to industry development.

### **Garlic**

For garlic in Ninh Thuan province, further investigation into the constraints of crop productivity on sands is required. There appears to be deterioration in garlic yield and quality in Ninh Thuan (Nguyen Van Bang and McKay 2015). Investigation of the causes and remedies is suggested, including assessing the quality and virus status of planting material. Some government-sponsored programs are already underway to assist farmers to improve productivity. Assessment of the impact of this work should precede any future research on these crops. There is strong need for coordination of information sharing in the garlic value chain. Future work should occur under the framework of collective action, including a grower association and consideration of cooperative marketing, a good agricultural practices (GAP) system, quality management and regional branding.

### **Labour saving**

Innovations that can release farm labour for other work should be a high priority for SCC Vietnam. Considerable labour savings have been seen in mini-pan irrigation and fodder management. Aside from the obvious economic considerations, there are possible social impacts since household labour can be better directed to other income-earning opportunities. In addition, the younger generations are not keen in taking up agricultural or processing-related jobs, which may create a labour shortage that hampers agricultural industry in SCC Vietnam (e.g. Nguyen Duy Duc and Pham Nhat Hanh 2015).

## **Soil constraints and their alleviation**

The occurrence of potassium (K) and sulfur (S) deficiencies on all the sands tested in SCC Vietnam (Bell et al. 2015; Hoang Minh Tam et al. 2015) suggests that these elements need greater emphasis in crop nutrient management. However, research on rates, forms, method of placement and timing of application should underpin the development of fertiliser recommendations for these elements. This needs to be supplemented by on-farm demonstration of the efficacy of the packages designed. The supply chain also needs to be analysed to ensure that suitable fertiliser products are available and are marketed in the area of sands where K and S are essential for productive crop production.

The discovery of micronutrient deficiencies (especially boron (B) and copper (Cu)) on the sands investigated in SCC Vietnam opens new opportunities for increased crop productivity (Bell et al. 2015; Hoang Minh Tam et al. 2015; Hoang Vinh et al. 2015a). However, accurate diagnosis is needed to determine which micronutrients will be deficient, since the suite of deficient micronutrients varies among sand types (Hoang Minh Tam et al. 2015). As with K and S, research on optimal rates, forms, methods of placement and timing of application should underpin the development of recommendations. Crop differences in sensitivity to micronutrients will also need to be determined. Fertiliser companies should be involved in designing and marketing of appropriate micronutrient fertiliser products for crops grown on sands. This needs to be supplemented by on-farm demonstrations of the efficacy and profitability of the crop nutrition packages designed.

The positive responses of peanut on sands in Phu Cat district, Binh Dinh province, to a range of nutrients (K, S, Cu, B, molybdenum), to biochar and to manure suggest that optimising nutrient supply needs an integrated nutrient management (INM) approach (Hoang Vinh et al. 2015a). Given the range of variables that affect nutrient supply, and their interaction with irrigation management, a systematic research program is required over the next several years to optimise nutrient and water supply for annual and perennial crops on sands of SCC Vietnam. The implications of this research for other provinces in the SCC region (Binh Thuan, Ninh Thuan, Khanh Hoa, Phu Yen, Quang Nam, Quang Ngai) need to be considered. It is clear that improvements in yield and

profit can be achieved by better managing nutrients and water for crop production but further work is needed on designing and demonstrating profitable packages of practices for farmers. There is potential to use variable inputs across orchards to maximise the profitability of fertiliser and irrigation inputs (Hall and Hoang Vinh 2015). A widespread program to identify nutrient deficiencies and make nutrient management recommendations would greatly improve farmer incomes.

In both Australia and Vietnam, promising results from biochar application suggest it could be a profitable soil amendment material that boosts crop productivity on sands (Hall and Bell, *in press*; Hoang Vinh et al. 2015a). Positive effects of biochar on nutrient supply need to be balanced against the risk of increased phosphorus leaching from some forms of biochar (data not shown). The underlying mechanism behind crop responses to biochar on sands needs further study. In the study of Hall and Bell (*in press*) on sands of the southern coastal region of Western Australia, the main benefit of biochar was nutrient supply, but this boosted crop production for only 3 years before the supply was exhausted. Promising results with biochar application on sands in Phu Cat district suggest that a value-chain analysis of this product would be worthwhile to understand how research can intervene to commercialise this technology so that products are available to farmers. Rice husks, which are available in large quantities, dispersed across the region, are a prospective stock for biochar production. However, a business case for producing and marketing the biochar needs to be developed. Even where biochar is not a feasible option, there is a range of organic resources available and used on farms in SCC Vietnam and positive effects on crop yield and nutrient balance are evident from studies (Hoang Thi Thai Hoa et al. 2015a, b; Hoang Minh Tam et al. 2015).

The mini-pan technique is a valuable tool for simple scheduling of irrigation water. It must be calibrated for each crop but there is considerable potential for reduction in water use and labour if further work is directed at this. Already, substantial reduction in water use to grow peanut has been demonstrated when scheduling applications of water according to the mini-pan technique (Hoang Vinh et al. 2015b). A strategy to take this finding forward for adoption by farmers is needed. Labour-saving and more efficient water delivery methods also need to be explored as alternatives to the present reliance on

hand-held hoses to irrigate crops. On-farm evaluation of a range of technologies such as sprinklers, sprayers and drippers is needed to identify the methods most suitable for farmers in SCC Vietnam as is training in the design and management of irrigation systems.

The addition of clay to sands in Western Australia has consistently increased crop yields by 20–80% (Hall et al. 2010). These increases have been attributed to more even wetting of the soil resulting in improved crop emergence, to nutrient addition (in particular, K) and to nutrient retention due to the higher CEC of clay compared with sand. The addition of 100 tonnes (t) of clay/ha increased soil CEC by 1.7 cmol/kg while also increasing soil carbon by 0.2% (Hall et al. 2010). The addition of clays to soils is currently practised in a limited way in SCC Vietnam and the benefits of clay addition have been demonstrated on sands in Phu Yen (Do Thi ThaiTruc, personal communication). Vegetable yields increased by 40–70% in sands amended with local clay from nearby paddy fields in An Chan commune. The attraction of clay amendment of sands is that it results in a permanent increase in water and nutrient retention. However, sourcing sufficient quantities of suitable clay from on-farm or off-farm sources and demonstrating their efficacy and profitable use in the SCC region requires more thorough investigation.

## **Integration of cropping and livestock systems**

Mixed crop–livestock farms are common in SCC Vietnam and enable farmers to diversify income and access potential complementarities between livestock and cropping. Levels of integration range from very little (where crops and livestock are present on the same farm but managed separately) to highly integrated systems (where outputs from one activity are inputs for another activity). A range of pathways for interaction does exist, including manure for crop production, livestock for traction and grazing, residues in crop production, and use of crop stovers for animal production. Forage crops for livestock can also be used as part of a cropping rotation.

Manure is a valuable output of livestock systems, and the amount collected increases as cattle are managed under more intensive stall-feeding systems rather than extensive grazing systems. Farmers typically apply manure to the first rice crop early in the year. Following this, the majority of farmers sell manure to collectors and traders, who arrange

transfer to farmers in the highlands. Manure can provide an important source of supplementary income; however, the implications for management of on-farm nutrient balances are unclear.

There are potential economic benefits of mixed crop–livestock systems. Livestock production can offer an alternative means of income generation, potentially with better income than solely from cropping. Alternatively, cattle can provide a less seasonal source of income than crop production alone. Having a readily saleable asset (like cattle or other livestock) could help smooth income and allow households to respond to various shocks for which they need income, as has been observed in other systems. Not all farmers choose to invest in livestock in addition to cropping. Building a breeding herd can take producers a significant amount of time, even if all breeding animals are kept rather than sold. Producers either require access to capital to be able to make a sizeable initial investment, or have another source of income to provide for household needs while stock numbers are increasing without generating income from sales.

A greater level of crop–livestock integration does not necessarily result in increased income. Traditionally, farmers use rice straw, a poor-quality animal feed, because other feeding options are limited. Farmers with access to higher quality stovers, such as peanut tops, are likely to offer these to cattle. Farmers who have access to common grazing lands will often take advantage of this opportunity, because it is ‘free’ and requires little or no economic investment (if time is not taken into account, e.g. Ninh Thuan). Crop–livestock systems generally become more integrated as population pressure increases and land becomes less available, possibly also due to grazing restrictions on common land. Under these circumstances, farmers are forced to consider other methods of feeding their cattle, providing an opportunity for introducing improved forage systems.

### **Spreading the impact of key findings**

Significant progress was reported in these proceedings on realising opportunities for improved productivity and sustainability of crop and livestock production on sands in selected cropping systems in SCC Vietnam. However, the studies were designed to examine representative locations within the region without being a comprehensive or exhaustive coverage of the issues. Moreover, the focus was on sands in

each study area. Hence, there is a need to place these results in context in the SCC region to determine the domains where they are relevant and the likely gaps that should form the basis for ongoing studies.

### **Geographical scope**

A geographically restricted selection of soils has been investigated in detail in SCC Vietnam (Bell et al. 2015). The detailed studies were restricted to one district in each of three provinces, and generally most of the work was done in a single commune covering 5,000–10,000 ha in that district. Even though study sites were selected to be representative of a broader region, there is a need to broaden the geographical scope of further studies on sands of SCC VN and possibly to north-central coastal (NCC) Vietnam. There is likely to be a greater diversity of sands encountered in a systematic region-wide soil survey of the coastal sandy terrain. Moreover, the range of other soils that occurs interspersed with the sands, particularly the heavier textured soils on the lowlands (where rice production is concentrated), need to be incorporated into a landscape-scale understanding of land and water management and agricultural systems.

The climate in the northern provinces of SCC Vietnam (Quang Ngai to Binh Thuan) and of NCC Vietnam (Thua Thien Hue to Ha Tinh) differs from that encountered in the present study and hence this influence needs to be factored into the conclusions drawn. Thua Thien Hue and Quang Nam have much higher total rainfall and more intense rainfall during September–November. Unlike other locations, these provinces also have an extended rainy season with nearly 200 mm of rainfall in January. The range of temperatures is also greater in these two provinces than around the city of Vinh to the north or Ninh Thuan to the south. The minimum temperature, especially during winter, increases with the progression southwards. These differences may affect water and nutrient use efficiency and crop productivity.

### **Soils**

The sands examined already show considerable diversity in properties. Parent materials and geomorphic origin of the parent material appear to explain most of the variation (Bell et al. 2015), although there was evidence of changes in soil properties due to management practices. More detailed studies are needed to define the full range of sands in central Vietnam and develop techniques for efficient use of water and nutrient management systems on these

sands. Based on research to date (Bell et al. 2015; Hoang Minh Tam et al. 2015; Hoang Vinh et al. 2015a; Hoang Thi Thai Hoa et al. 2015a, b), the best management practices are likely to involve complete nutrient supply (including K, S and micronutrients), addition of soil amendments and more efficient irrigation techniques.

### **Low rainfall zone**

The low rainfall zone in Ninh Thuan and Binh Thuan provinces remains a challenge for research and for agricultural productivity. The unpredictable rainfall regime suggests that long-term research programs are needed to thoroughly explore new options for productivity, resilience and sustainability. A more opportunistic and flexible approach to rainfed cropping should be pursued in the coastal zone of these provinces based on patterns of in-season rainfall (some opportunities may only be worth pursuing when heavy rain falls), supplemented by animal production, agroforestry and small-scale irrigation, where water resources permit. Consideration also needs to be given to institutional capability to mount and maintain a long-term research and development program in these provinces.

### **Livestock and forages**

The present project has examined only forages and cattle production (Nguyen Huu Van et al. 2015; Nguyen Xuan Ba et al. 2015). However, small ruminants (sheep and goats) also have great potential for SCC Vietnam, due to their smaller body size and greater affordability for smallholders. For livestock and smaller ruminants, supplemental feeding options could be further explored for improved animal nutrition and health through a combination of feeding experiments and modelling. There would be value in the development of a decision-support tool to help extension agents give tailored advice to individual farmers given the range of available feeding options and prices. As the issues with feeding limitations become less widespread due to improved livestock nutrition, there will be a need to focus on other constraints for cattle production, including breeds and meat quality.

The project focused on encouraging farmers to move from extensive grazing of cattle to semi-intensive stall-feeding, in order to reduce labour, increase production and relieve pressure on common lands (Nguyen Huu Van et al. 2015; Nguyen Xuan Ba

et al. 2015). However, in some areas, particularly in Ninh Thuan province, there is opportunity to develop land management strategies for extensive areas of privately owned dryland areas, but long-term research and development would be needed to design grazing management systems that are both productive and sustainable on these easily degraded sands. Mineral deficiencies, particularly in sheep, remain a largely unexplored area of research for animals reliant on feed produced on infertile sands, and could be reducing production and quality. For example, in Hoang Minh Tam et al. (2015), we have identified deficiencies of copper on most sands plus deficiencies of zinc and molybdenum on some sands. The low levels of these micronutrients, and of sulfur, may be impairing animal nutrition and hence animal productivity and on the supplementation of these nutrients for humans through the food value chain.

While major production gains were demonstrated with the production and feeding of forage grasses, leucaena is proving to be highly adapted to SCC climate and soils, and could play a major role in providing protein for ruminant production. However, it is essential that the issues which may threaten its success, such as variety selection, pests and toxicity, are monitored for future adoption.

### **Groundwater resources**

There are significant knowledge gaps in the agriculture sector about the groundwater resources of the study area (Keen and Chu Thai Hoanh 2015). Widespread dependence on groundwater for irrigation in SCC Vietnam suggests that greater understanding of this resource is required by farmers and agricultural officers at commune and provincial levels to sustainably manage it. Critical information requirements for agriculture in the SCC region include: the size of the groundwater resource; annual recharge rates; the underlying hydrogeological structure of the aquifers; competing uses for groundwater; and current rates of abstraction by all users. Further study should examine the sustainability of this resource given current and projected future rates of exploitation. The risk from pollution of groundwater and surface water by fertiliser, animal waste, human settlements and agricultural chemicals (Do Thi Thai Truc et al. 2015) and from saline intrusion due to over pumping on the coastal zone also needs more thorough investigation.



## Improving the analysis of economic drivers of productivity improvement

During the value-chain studies, it became evident that there are only limited tools for farmers to assist with decision-making for crop and farming systems to respond more rapidly to market signals within the constraints of available land, labour and credit. The Farm Economic Model (FEM) was developed and evaluated by potential users as a tool for assessing the profitability of farming systems involving annual and perennial cropping as well livestock enterprises (Summers et al. 2013). The model has received good support from regional Department of Agricultural and Rural Development (DARD) staff. Further training of SCC DARD staff in both basic economic enterprise analysis and use of the model would support more informed crop and farming system decision-making by farmers. There is scope for the use of this tool in the generation and development of regional or provincial models to estimate or project the financial and logistical impact of proposed interventions or changes to cropping enterprises or infrastructure. The keys to achieving such a goal are skills in Excel modelling and understanding of farm management techniques and approaches. Further investment in training would be required to achieve this. Incrementally, the collection and collation of enterprise data placed into such a framework would make this a very powerful decision-making tool for investors in agricultural farming systems and in development of SCC Vietnam.

## Building capacity

The above analysis reveals a diverse range of challenges and opportunities for the development of profitable and sustainable agriculture in SCC Vietnam. Realising the benefits of these opportunities and tackling the challenges requires a strengthening of skills and capacity in the region in public research and extension institutions and in the private sector, particularly in the food supply and market chains. The key priorities for capacity building are in: identification of bottlenecks in the value chains of agricultural produce and then in the design and implementation of effective interventions; irrigation design and technology; nutrient management for upland crops on sands; integration of productive livestock enterprises with crop production on smallholdings; planning for sustainable and productive groundwater use; and nutrient management strategies to minimise pollution of shallow groundwater.

## Conclusions

While agriculture in SCC Vietnam is hampered by distance from major markets, low fertility sands and the long dry season, the present studies point to promising interventions to improve profitability and sustainability. Labour saving was identified as a priority for cattle producers and farmers practising irrigation with hand-held hoses. Expansion of beef-cattle production was a promising option for the SCC region, especially when integrated with cropping. Productivity increases of mango, cashew and peanut are feasible with improved varieties, soil nutrient and water management. Promising technologies were identified for increased water use efficiency. These technologies may help to reverse excessive exploitation of groundwater, especially in peanut production areas of Binh Dinh province. Reduced nutrient pollution of groundwater also warrants more attention. For mango, off-season production is a great opportunity for expansion of production and increased value, especially in Binh Dinh. For cassava, environmentally sustainable cultivation techniques should be improved and extended to farmers; technologies that increase price and decrease price volatility are a high priority. By contrast, realistic assessments are needed to determine the areas where continued production of cashew should be promoted. The present findings have relevance for the whole of the coastal central region of Vietnam where sands are prevalent.

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