IWMI Working Paper

183

Community-managed Groundwater Irrigation on the Vientiane Plain of Lao PDR: Planning, Implementation and Findings from a Pilot Trial

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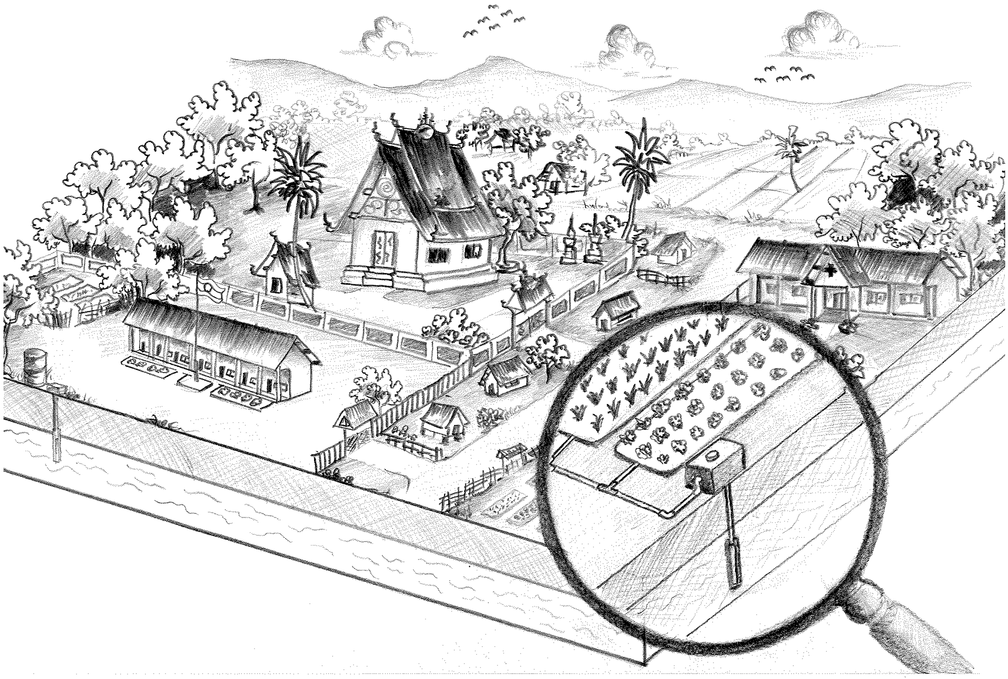

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Cover image: Community-managed groundwater irrigation in Laos. Artist's impression by Mr. Parndaeng Vilai.

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Project

This study is an output of the *Enhancing the resilience and productivity of rainfed dominated systems in Lao PDR through sustainable groundwater use* project, with financial assistance from the Australian Centre for International Agricultural Research (ACIAR) through project no. LWR/2010/081. Project activities were carried out under the management of Dr. Evan Christen (ACIAR). Project website: http://gw-laos.iwmi.org.

Collaborators

International Water Management Institute (IWMI)

Ministry of Agriculture and Forestry, Department of Irrigation (DoI)

Institute for Global Environmental Strategies (IGES)

Donors

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Contents

List of Figures

Figures in Appendices

List of Tables

Tables in Appendices

Acronyms and Abbreviations

BCR	Benefit-Cost Ratio
DAFO	District Agriculture and Forestry Office (Lao PDR)
DoI	Department of Irrigation (Lao PDR)
DWR	Department of Water Resources (Lao PDR)
EDL	Electricité du Laos
ETc	Actual crop evapotranspiration
ETo	Reference evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
GWUG	Groundwater User Group
IR	Irrigation water requirement
IRR	Internal Rate of Return
IWMI	International Water Management Institute
Kc	Crop coefficient
MoU	Memorandum of Understanding
NPV	Net Present Value
PAFO	Provincial Agriculture and Forestry Office (Lao PDR)
PDR	People's Democratic Republic (Laos)
PE	Polyethylene
PVC	Polyvinyl Chloride
ToR	Terms of Reference
WUA	Water Users Association

Executive Summary

Irrigated agriculture has become an important focus of the Government of Lao People's Democratic Republic (PDR) for addressing poverty alleviation, food security and climate change. Most irrigation systems to date have relied upon surface water, limiting irrigation development to areas close to streams, rivers and reservoirs. To address this gap, a community-managed groundwater irrigation pilot trial was specifically established on the Vientiane Plain. This trial, believed to be the first of its kind in the country, was established to assess the technical performance, economic viability and effectiveness of the institutional arrangements. This paper first covers the approach followed during project implementation, including the means by which the system was sited, designed and built together with the newly-formed Groundwater User Group (GWUG). Second, it describes the monitoring conducted over two successive dry seasons of cultivation to establish the system performance. Finally, the key lessons from the trial are drawn out and discussed. To enable greater farmer adoption, all pumping costs and some maintenance costs were covered by the project for the first year of dry-season cultivation only.

Farmers cultivated a mix of paddy rice and cash crops using a combination of irrigation technologies (furrow, sprinkler and drip). Diversification through cash crop cultivation was found to generate substantial profits (both with and without the project subsidy for pumping/maintenance costs), while rice cultivation was only profitable with the subsidy. Farmers cultivating non-rice crops generated actual profits over the two dry seasons ranging from USD 115 to USD 1,042 (LAK 0.9 to 8.5 million) per season. A financial analysis based on the data collected during the first year of operation reaffirms that the irrigation system would only be attractive to farmers if cash crops were cultivated. Farmers tended to over-irrigate relative to crop water requirements, indicating that water productivity could be increased considerably through more efficient irrigation application and wider uptake of water-saving technologies. Financial viability of the system is ultimately dependent on the level of adoption by farmers, the type of crops cultivated and choice of agricultural practices. Improved fertilizer management and greater orientation towards more market-oriented crops would help increase farmer profits. During the first year of operation, the pilot trial was able to clear some of the initial doubts of the farmers about groundwater availability and irrigation costs. This was because the system was able to provide a reliable source of water at a relatively low cost, even during the peak dry season when alternative water sources, including minor canals and shallow wells, dry out.

Levels of farmer adoption in the pilot trial were surprisingly modest in both years. Four farmers irrigated a total area of 1.52 ha in the first dry season and only one farmer irrigated 0.67 ha in the second dry season when the subsidy was removed. Farmers opted out of dry-season irrigation primarily due to a lack of household labor, often pursuing more attractive income-generating off-farm activities. Also, farmers' engagement in alternative livelihood options and limited external technical support were further reasons for non-adoption of the irrigation system. Our results highlight that a detailed upfront understanding of farmers' needs, traditional value systems and practices linked to cultivation and food security, existing livelihood options and socioeconomic status are as important as understanding the groundwater resource capacity and irrigation demand, in order to maximize adoption and ensure sustainability of the irrigation system. The development potential of groundwater for irrigation in Lao PDR is high and the lessons drawn from this study serve to provide wider opportunities for agricultural groundwater development in Lao PDR.

ການຄຸ້ມຄອງຊົນລະປະທານນ້ຳໃຕ້ດິນຂອງຊຸມຊົນເພື່ອການ ກະສິກຳຢູ່ ທົ່ງພຽງວຽງຈັນ, ສປປ ລາວ:

ການວາງແຜນ, ການຈັດຕັ້ງປະຕິບັດ ແລະ ຜົນຂອງການສຶກສາຢູ່ຈຸດທົດລອງ

ໂກເລຕິນ ແກຼແມັນ, ຈໍແດນ ວິກເກາບເລເກລ, ໂປນ ພາວາລິກ, ກ້ອງຊົ່ງ, ເລັ່ງຢ່າ ທວາລີ, ຕູ້ລີລົ່ ໄຊຕຸກີ, ບີນາຢາ ຫຼາກ ຊີວາໂກຕີ ແລະ ທ່ານ ຄຳໄມ ວົງສະຖຽນ

ບົດຄັດຫຍໍ້

ວຽກງານຊົນລະກະເສດເປັນວຽກຈຸດສຸມທີ່ສຳຄັນຂອງລັດຖະບານແຫ່ງສາທາລະນະລັດ ປະຊາທິປະໄຕ ປະຊາຊົນລາວ ເພື່ອການແກ້ໄຂຄວາມທຸກຍາກ, ການຄ້ຳປະກັນດ້ານສະບຽງອາຫານ ແລະ ການຮັບມືຕໍ່ປ່ຽນແປງດິນຟ້າອາກາດ. ສ່ວນຫຼາຍລະບົບຊົນລະປະທານທີ່ມີໃນປະຈຸບັນແມ່ນອີງໃສ່ແຫຼ່ງນ້ຳໜ້າດິນເປັນຫຼັກ, ແຕ່ວ່າການພັດທະນາລະບົບຊົນລະປະທານໃນພື້ນທີ່ທີ່ໃກ້ຄຽງສາຍນ້ຳ, ລ້ອງນ້ຳ ແລະ ອ່າງເກັບນ້ຳຕ່າງໆຍັງມີຂໍ້ຈຳກັດ. ເພື່ອແກ້ໄຂຊ່ອງຫວ່າງດັ່ງກ່າວ, ຈຶ່ງໄດ້ສ້າງກຸ່ມຄຸ້ມຄອງຊົນລະປະທານນ້ຳໃຕ້ດິນຂອງຊຸມຊົນນີ້ຂຶ້ນມາເພື່ອເປັນພື້ນທີ່ທົດລອງ,ເຊິ່ງພື້ນທົດລົງນີ້ຕັ້ງຢູ່ທົ່ງພຽງວຽງຈັນ.ພື້ນທີ່ທົດລອງດັ່ງກ່າວເຊື້ອວ່າເປັນພື້ນທີ່ທຳອິດທີ່ໄດ້ຈັດຕັ້ງປະຕິບັດຢູ່ໃນ ສປປ ລາວເພື່ອເປັນການສາທິດ, ການປະເມີນທັງດ້ານເຕັກນິກ, ລວມທັງຄວາມສາມາດດ້ານເສດຖະກິດ ແລະ ປະສິດທິພາບຂອງການຈັດຕັ້ງສະຖາບັນ. ບົດລາຍງານສະບັບນີ້. ອັນທີ່ໜຶ່ງ, ແມ່ນອະທິບາຍເຖິງວິທີການຈັດຕັ້ງປະຕິບັດໂຄງການເຊັ່ນ: ການອອກແບບ ແລະ ການກໍ່ສ້າງກຸ່ມນຳໃຊ້ນ້ຳ, ພາຍໃຕ້ການປະສານສົມທົບກັນລະຫວ່າງກຸ່ມນຳໃຊ້ນ້ຳເກົ່າ ແລະ ສ້າງກຸ່ມນຳໃຊ້ນ້ຳໃໝ່. ອັນທີ່ສອງ, ແມ່ນອະທິບາຍເຖິງການຕິດຕາມ ແລະ ການຈັດຕັ້ງປະຕິບັດກ່ຽວກັບການປູກພືດຢູ່ໃນລະດູແລ້ງ, ສອງລະດູທີ່ໄດ້ຈັດຕັ້ງປະຕິບັດສຳເລັດຢູ່ໃນພື້ນທີ່ທົດລອງດັ່ງກ່າວນີ້. ທັງສຸດທ້າຍນີ້, ແມ່ນອະທິບາຍເຖິງບົດຮຽນສຳຄັນທີ່ຖອດຖອນໄດ້ຈາກການຈັດຕັ້ງປະຕິບັດ ແລະ ການປຶກສາຫາລື.

ເພື່ອໃຫ້ເປັນການຈູງໃຈຊາວນາ, ໂຄງການສາທິດຢູ່ພື້ນທົດລອງນີ້ໄດ້ຊ່ວຍຊາວກະສິກອນຈ່າຍຄ່າດູດນ້ຳ ແລະ ຄ່າບຳລຸງຮັກສາປ້ຳນ້ຳຈຳນວນໜຶ່ງໃນການປູກພືດລະດູແລ້ງຂອງປີທຳອິດ.ປີທຳອິດ, ຊາວກະສິກອນໄດ້ປູກເຂົ້າປະສົມກັບການປູກພືດເສດຖະກິດຈຳນວນໜຶ່ງໂດຍນຳໃຊ້ເຕັກນິກຊົນລະປະທານທີ່ແຕກຕ່າງກັນເຊັ່ນ: (ລະບົບໄຫຼຖ້ວມ, ລະບົບສີດຝອຍ ແລະ ລະບົບຢອດ). ຜ່ານການປູກພືດເສດຖະກິດແບບປະສົມປະສານນັ້ນເຫັນວ່າມີຜົນກຳໄລດີຫຼາຍ (ເຖິງແມ່ນວ່າຈະໄດ້ຮັບການອູດໜູນ ຫຼື ບໍ່ໄດ້ຮັບການອູດໜູນຈາກໂຄງການກໍ່ຕາມ).ໃນຂະນະດຽວກັນນັ້ນເຫັນວ່າການປູກເຂົ້າແມ່ນບໍ່ມີກຳໄລ, ໄດ້ພໍ່ຕົ້ນທຶນຄືນເທົ່ານັ້ນ. ເນື່ອງຈາກວ່າການປູກເຂົ້າແມ່ນຕ້ອງການນ້ຳຫຼາຍກ່ວາພືດອື່ນໆແຕ່ໄລຍະຜ່ານມາຜົນຜະລິດພັດກົງກັນຂ້າມລາຄາພືດພັດຕ່ຳກ່ວາເປົ່າໝາຍ ຊາວກະສິກອນຜູ້ທີ່ປູກພືດເສດຖະກິດອື່ນໆທີ່ບໍ່ປູກເຂົ້າສາມາດສ້າງລາຍຮັບຕະຫຼອດສອງລະດູແລ້ງນີ້ໄດ້ເຖິງ 115 ໂດລາ ຫາ 1042 ໂດລາ (ຄິດເປັນເງິນກີບ 9 ແສນ ຫາ 8.5 ລ້ານກີບ) ຕໍ່ລະດູການໜຶ່ງ. ຕາມການວິເຄາະດ້ານການເງິນໂດຍອີງໃສ່ຂໍ້ມູນທີ່ເກັບໄດ້ໃນຊ່ວງປີທຳອິດຂອງການດຳເນີນງານສະແດງໃຫ້ເຫັນວ່າລະບົບຊົນລະປະທານນີ້ມີຄວາມດຶງດູດຊາວກະສິກອນເປັນທາງເລືອກທີ່ດີໃນການປູກພືດເສດຖະກິດເທົ່ານັ້ນ. ຕາມການຕິດຕາມເຫັນວ່າຊາວກະສິກອນສະໜອງນ້ຳໃຫ້ແກ່ພືດຂ້ອນຂ້າງເກີນຄວາມຕ້ອງການນ້ຳຂອງພືດ, ອັນນີ້ສະແດງໃຫ້ເຫັນວ່າການນຳໃຊ້ນ້ຳຍັງສາມາດສະໜອງໄດ້ເນື້ອທີ່ທີ່ຫຼາຍກ່ວານີ້ ຖ້າຫາກພວກເຮົາຫາກມີການຄຳນຶງເຖິງລະບົບຊົນລະປະທານ ທີ່ມີປະສິດ ທິພາບ ແລະ ມີການນຳໃຊ້ເຕັກໂນໂລຊີທີ່ປະຢັດນ້ຳ. ຄວາມສາມາດດ້ານການເງິນຂອງລະບົບນີ້ແມ່ນຂຶ້ນກັບລະດັບການນຳໃຊ້ຂອງຊາວກະສິກອນ, ໂດຍສະເພາະແມ່ນຕ້ອງຄຳນຶງເຖິງຊະນິດພືດທີ່ຈະປູກ ແລະ ເລືອກວິທີການປູກ. ການຍົກລະດັບການຈັດການຝຸ່ນ, ປູກພືດທີ່ຕະຫຼາດຕ້ອງການ ແລະ ມີວິທີການເຂົ້າຫາຕະຫຼາດໃຫ້ດີເປັນສິ່ງທີ່ຈະສາມາດຊ່ວຍໃຫ້ຊາວກະສິກອນມີຜົນກຳໄລຫຼາຍຂຶ້ນ. ການດຳເນີນໂຄງການທົດລອງຊ່ວງໄລຍະປີທຳອິດກໍ່ສາມາດຕອບຄຳຖາມ ແລະ ຂໍ້ສົງໄສຂອງຊາວກະສິກອນ ກ່ຽວກັບປະລິມານນ້ຳທີ່ມີຢູ່ໃນບໍ່ນ້ຳບາດານ ແລະ ຄ່າໃຊ້ຈ່າຍຕ່າງໆຂອງລະບົບຊົນລະປະທານນີ້.ລະບົບຊົນລະປະທານນີ້ດຳເນີນໄດ້ດີເນື່ອງຈາກວ່າມັນສາມາດສະໜອງໄດ້ນ້ຳພຽງພໍດ້ວຍຕົ້ນທຶນຕ່ຳ, ເຖິງແມ່ນວ່າຢູ່ໃນລະດູແລ້ງ ແລະ ເວລາແລ້ງສຸດທີ່ລະບົບຄອງຊົນລະປະທານທີ່ມີ ແລະ ນ້ຳສ້າງຢູ່ອ້ອມຂ້າງກໍ່ບົກແຫ້ງໝົດ.

ການຈັດຕັ້ງປະຕບັດຢູ່ພື້ນທົດລອງນີ້ໄດ້ດຳນິນຂ້ອນຂ້າງແປກໃຈຕະຫຼອດໄລຍະສອງປີເພາະໃນລະດູແລ້ງຂອງປີທຳອິດມີຊາວກະສິກອນຈຳນວນສີ່ຄົນປູກພືດໃນເນື້ອທີ 1.52 ເຮັກຕາ, ແຕ່ມາຮອດປີທີສອງມີພຽງແຕ່ຜູ້ດຽວທີ່ປູກ ແລະປູກໃນເນື້ອທີ່ 0.67 ເຮັກຕາເທົ່ານັ້ນຫຼັງຈາກທີ່ໂຄງການບໍ່ມີທຶນສະໜັບສະໜູນແລ້ວ. ຊາວກະສິກອນສ່ວນຫຼາຍບໍ່ປູກພືດໃນລະດູແລ້ງກໍ່ເນື່ອງຈາກຂາດແຮງງານໃນຄົວເຮືອນ, ນອກນັ້ນຊາວກະສິກອນກໍ່ມີລາຍໄດ້ດີຈາກວຽກອື່ນໆທີ່ບໍ່ ແມ່ນວຽກກະສິກຳແລະ ເຂົາກໍ່ມີທາງເລືອກຫຼາຍໃນການດຳລົງຊີວິດທີ່ບໍ່ອາໄສການຊ່ວຍເຫຼືອດ້ານເຕັກນິກວິຊາການຈາກພາຍນອກນັ້ນເປັນເຫດຜົນໜຶ່ງທີ່ເຂົາບໍ່ມີຄວາມສົນໃຈທີ່ນຳໃຊ້ລະບົບຊົນລະປະທານນີ້ຢ່າງເຕັມສ່ວນ. ຜົນໄດ້ຮັບຈາກການສຶກສາຄັ້ງນີ້ໄດ້ເຂົ້າໃຈລະອຽດກ່ຽວກັບ ຄວາມຕ້ອງການຂອງຊາວກະສິກອນ, ເຂົ້າໃຈຮູບແບບການນຳໃຊ້ລະບົບຊົນລະປະ ທານແບບດັ້ງເດີມ ແລະ

ຮູບແບບການປູກຝັງທີ່ຜ່ານມາທີ່ເຊື່ອມໂຍງກັບການຄ້ຳປະການດ້ານສະບຽງອາຫານ, ທາງເລືອກການດຳລົງຊີວິດ, ສະພາບເສດຖະກິດສັງຄົມທີ່ມີຢູ່ແມ່ນປັດໃຈສຳຄັນທີ່ຈະເຂົ້າໃຈເຖິງຄວາມສາມາດດ້ານແຫຼ່ງຊັບພະຍາກອນນ້ຳໃຕ້ດິນ ແລະ ຄວາມຕ້ອງການດ້ານຊົນລະປະທານຂອງຊາວກະສິກອນ ແລະ ກໍ່ເປັນປັດໃຈເພື່ອເຂົ້າໃຈເຖິງນຳໃຊ້ໃຫ້ເກີດຜົນປະໂຫຍດສູງສຸດພ້ອມທັງຮັບປະການຄວາມຍືນຍົງຂອງລະບົບຊົນລະປະທານ. ການພັດທະນາວຽກງານຊົນລະປະທານນ້ຳໃຕ້ດິນຢູ່ ສປປ ລາວ ແມ່ນເຫັນວ່າມີທ່າແຮງສູງ. ບົດຮຽນທີ່ຖອດຖອນມາໄດ້ຈາກການສຶກສາຄັ້ງນີ້ແມ່ນເປັນທິດທາງທີ່ດີ ແລະ ເປັນການເປີດໂອກາດໃຫ້ແກ່ການພັດທະນາວຽກງານກະສິກຳທີ່ນຳໃຊ້ນ້ຳໃຕ້ດິນຢູ່ໃນ ສປປ ລາວ.

INTRODUCTION

There has traditionally been limited dependence on groundwater in Lao People's Democratic Republic (PDR) owing to the vast potential of surface water resources (per capita availability of 50,000 cubic meters [m^3]/person/year [FAO 2013]; the highest in the Greater Mekong Subregion). Consequently, groundwater resources have remained highly underdeveloped. Although water-rich by most standards, Lao PDR still faces constraints in water availability, with water scarcity emerging as a major issue at specific times and locations (Khamhung 2002).

Use of groundwater for irrigation is expanding worldwide and represents more than 40% of the total area under irrigation (Siebert et al. 2010). Groundwater potentially offers Lao PDR a strategic niche resource that could compliment the more abundant, but highly seasonal and less evenly distributed surface water resources. In physical terms, groundwater presents a reliable (well-buffered) supply of generally good quality water that is available on demand. At the same time, energy is usually required for pumping groundwater, so economic considerations need to be taken into account. Also, groundwater resources are susceptible to overuse or pollution from poor land-use practices. In order to enhance the climate resilience of smallholder farmers, supplementary irrigation to account for wet-season rainfall deficits and localised access to water during the dry season are perceived as key strategies for climate change adaptation in Lao PDR and more widely in the subregion (Johnston et al. 2010).

In Lao PDR, groundwater use for irrigation is believed to cover an area of just 200 hectares (ha) (Siebert et al. 2010). This is entirely limited to individual (private) smallholder farmers or households drawing on the resource through shallow wells, largely in lowland areas (Pavelic et al. 2014; Vote et al. 2015). In a country still dominated by rainfed agriculture, irrigation has become an important thrust of the Government of Lao PDR for socioeconomic development, in particular, to improve food and nutrition security, and for poverty alleviation (GoL 2016). Having recognized the need to adopt approaches that involve the participation of farmers in all stages of development and management of irrigation projects, the government is encouraging community management to ensure more sustainable and profitable irrigation systems (GoL 2015).

In areas located far away from surface water sources or those that are prone to surface water scarcity, groundwater is gaining recognition as a valuable source of water for agricultural development. Expansion of small-scale groundwater irrigation offers an attractive option for smallholder farmers to overcome losses due to erratic rainfall and enhance food production in the dry season. At present, groundwater use for agriculture is limited to irrigation in the dry season from large open dug wells on agricultural fields or home gardening from domestic wells (hand-dug or drilled wells) on a limited scale. While this type of private groundwater development can be profitable (ACIAR 2016), the opportunities for scaling up this approach are limited to settings with shallow groundwater levels for better-off farmers who can afford the capital costs. The use of deeper boreholes that could provide larger and more reliable volumes of water have not been explored in Lao PDR.

To address this gap, the first-known, community-managed groundwater pilot irrigation system in Lao PDR was implemented in Ekxang village, situated on the Vientiane Plain. This pilot trial aims to evaluate the technical performance of groundwater irrigation, along with its participatory management, and thereby establish its potential for scaling up.

PREPARATION AND ESTABLISHMENT OF TRIAL

Village Selection

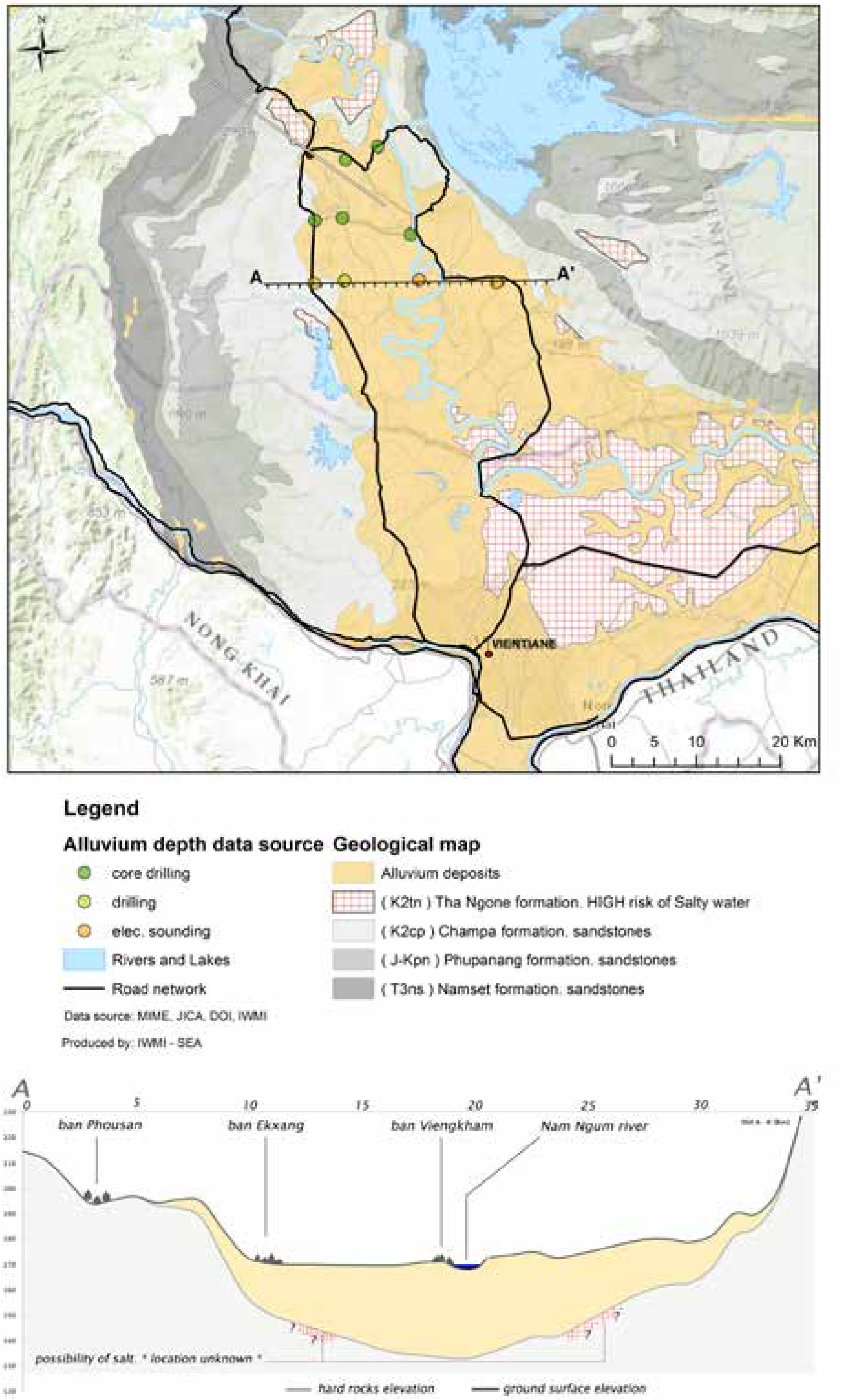
Selection of the location for the pilot trial first considered the opportunities at the broad scale, recognizing that the lowlands of Lao PDR hold the highest agricultural production potential. The Vientiane Plain was favored because it is one of the largest, most populated and perhaps the most economically important lowland plains in Lao PDR. With its 4,500 square kilometer (km^2) area, the focus of the study was on the upper (northern) region where large surface irrigation systems are absent, and past investigations suggested there were good prospects for further developing groundwater resources (Figure 1; ACIAR 2016).

The project team selected Ekxang village for the trial with its clear scope for expanding dry-season cropping due to the high groundwater resource potential. The village of 1,280 people is situated around 55 km north of Vientiane Capital and a short distance from the main all-weather road (i.e., Road No. 13). Thus, the site is easily accessible and offers good market access for the sale of produce. A meeting with the Ekxang Village Authorities in the presence of representatives from the District Agriculture and Forestry Office (DAFO) and the Provincial Agriculture and Forestry Office (PAFO) during the last quarter of 2012 confirmed that the village was mostly reliant upon groundwater for domestic and agricultural supplies due to limited surface water sources nearby. The shallow wells used by individual households for domestic use and home gardening are prone to drying out in the latter stages of the dry season. Deeper boreholes would offer more reliable irrigation water supplies and thereby reduce the risk of water shortages. The Village Authorities gave their full support to working with the project team to develop a community-level irrigation trial. A memorandum of understanding (MoU) was signed between the project team and the village prior to establishing the community-based groundwater irrigation trial.

Agriculture and Livelihoods

More than 80% of the 236 households in Ekxang village are involved in paddy cultivation, which is mostly rainfed during the wet season (Keophoxay et al. 2015) (Appendix 1, Table A1.1). Irrigation is largely concentrated in the open spaces within the village residential area. This is where a significant proportion of the households are involved in home gardening and cultivate a diverse range of vegetables and herbs (e.g., morning glory, Chinese cabbage, coriander, mint, lettuce and spring onion). Throughout the village, cash crops such as yard-long bean, watermelon and cucumber are typically cultivated in non-paddy areas. As an emerging trend, these cash crops are also increasingly being cultivated on paddy lands during the dry season. The source of water for irrigation is usually from shallow lined-dug (ring) wells for home gardening, and from large shallow open-dug wells for cash crop production. In ring wells, water is withdrawn using a bucket, a floating or a surface pump, reaching a pumping rate of 0.5 to 1 liter/second. In open-dug wells, water is pumped using a two-wheel tractor as a generator and a mobile surface pump, ensuring a pumping rate as high as 8 to 10 liters/second. Some surface water is brought in via a small canal from a neighboring village (i.e., Phontan) to cultivate cash crops or a second rice crop during the dry season. However, limited water availability during the dry season is a major constraint to cultivating these cash crops. Coverage by surface water canals in Ekxang village is very low, and these canals and many dug wells normally dry out during the dry season, usually around March or April. Further details about the agricultural systems and socioeconomic conditions of the village are provided by Suhardiman et al. (2016, Forthcoming), Maokhamphiou (2014) and Grant et al. (2015).

FIGURE 1. Hydrogeology of the Vientiane Plain indicating the location of Ekxang village (*ban* Ekxang) along transect A-A'.



Source: Adapted from ACIAR 2016.

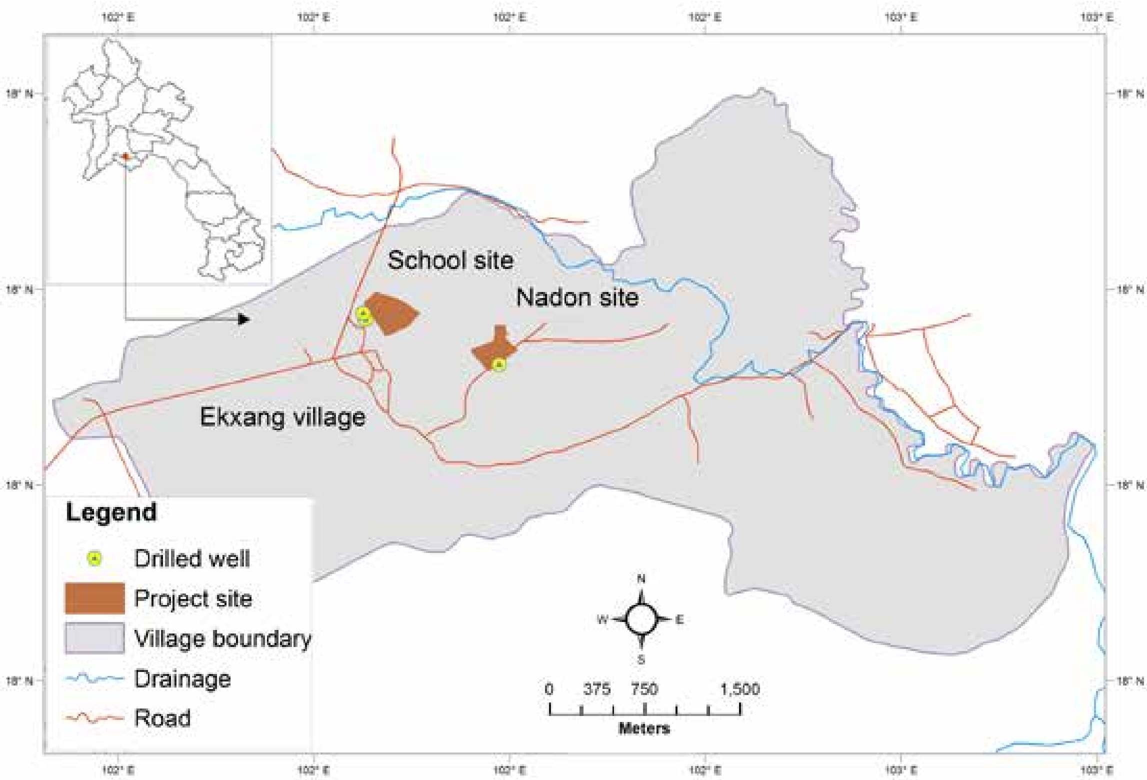
Groundwater Conditions

The Ekxang village area is mostly underlain by alluvial sediments with a total thickness of around 30 meters (m) (DoI 2014). The transmissivity of the alluvial aquifer ranges from 3 to 3,000 square meters (m^2)/day. Well yields can reach up to 10 liters/second. The groundwater table typically fluctuates from a depth of 3 m below ground level late in the wet season to a depth of 6 m late in the dry season. Water quality testing of the irrigation boreholes shows that the groundwater is of an acceptable pH, with acceptably low dissolved solids and nutrient contents (DoI 2014). Further details on groundwater suitability for irrigation and drinking purposes at the village scale can be found in Brindha et al. (2017). Apart from irrigation, groundwater is also widely used throughout Ekxang village for domestic purposes. In most households, electric pumps are used to lift groundwater from a shallow well (around 10 m deep) and stored in an elevated storage tank to ensure stable supplies.

Site Selection

Site inspections identified several prospective locations for the trial. The initial plan was to install three irrigation boreholes in close proximity to one another at one location. However, this was revised to two locations, as there was insufficient land available for drilling at any of these sites (assuming a minimum spacing of 50 m). Based on the available land and proximity to the electricity grid, a location close to the village school (hereafter referred to as the "school" site) was finally selected. Two boreholes were drilled at this location to supply water to the adjacent agricultural fields (Figure 2). Another location, known as the "nadon" site, was also selected. A borehole was also drilled at this site and equipped with a pump. Nadon is situated about 1 km southeast of the

FIGURE 2. Map of Ekxang village indicating the location of the trial site.



school and remote from the electricity grid, and hence relied on a diesel electric generator. Both sites are located within a large paddy cultivation area, which is also used in part for cultivation in the dry season. This paper focuses on the school site as the trial did not proceed at the nadon site due to the lack of adoption by farmers, as a result of the higher pumping cost (i.e., at least twice as expensive as compared to the school site).

Soil Conditions

Soils with high clay content can be found at the site with a soil texture varying from clay loam to sandy clay loam. Average soil density varies from 1.4 grams (g)/cubic centimeter (cm^3) near the surface to 1.7 g/cm^3 at 1 m depth, suggesting a hardpan layer at a depth of about 50 cm or higher that is characteristic of paddy cultivation. This suggests that the soil has a high water retention capacity but relatively low to medium infiltration rate (< 25 millimeters [mm]/day). According to the Munsell soil color charts (Munsell 1975), the soil color under dry conditions was mainly either "light grey" or "very pale brown", suggesting low organic matter content. Relatively higher organic matter content occurs near the surface due to crop residues. Soil hydromorphic conditions were clearly indicated by the pink color, revealing the presence of oxidized iron mostly found at depths of 50 to 100 cm. This data suggest that soil fertility management requires particular attention, since the low organic matter content and hydromorphic conditions might restrict the microbiological activity of the soil. In addition, the low infiltration rate may lead to runoff losses during irrigation events.

Construction of Irrigation System

Borehole Drilling and Testing

Pilot trial construction started in June 2014 with the drilling of two boreholes near the perimeter of the school adjacent to the paddy fields. The wells, identified as W01/14 and W02/14 (Figure 3), were positioned as far apart as possible (about 50 m) to minimize well interference effects. A rotary drilling rig was used to drill a 12-inch diameter hole. At a maximum drilling depth of 35 m, the electrical conductivity values of the groundwater reached as high as 1,600 to 1,800 µS/cm. Thus, both wells were backfilled by 3 m and completed at a depth of 32 m to avoid deeper brackish layers. The stratigraphic logs derived from cutting materials suggested that, below the topsoil layer, sand and gravel interspersed with clay to depths of up to 20 m. These layers are underlain by weakly weathered and fissured mudstones (DoI 2014). Both boreholes were fitted with an 8-inch diameter polyvinyl chloride (PVC) pipe. The slotted screen interval was from a 12 to 28 m depth with a 4-8 mm gravel pack added around the slotted interval.

Two production tests were carried out at borehole number W01/14 before the trial began. The first was in late August 2014 under high water table conditions and relatively low pump discharge. The second was in early July 2015 with higher pump discharge and deeper water table conditions in comparison with dry-season conditions. The specific capacity was higher during 2014 than 2015, confirming lower yield potential during the dry season (Table 1). A conservative pump discharge rate of 2.2 liters/second/borehole was applied. While well testing in 2014 and 2015 confirmed that the boreholes could handle discharge rates much greater than that acquired, the design rate was not changed.

The peak water demand for the irrigation system was derived from a maximum crop water requirement of 5 mm per day according to the range of crops cultivated in the village (Allen et al. 1998). According to the total design pump discharge rate of 4.4 liters/second, the peak demand could be met across an area of 7.6 ha. A conservative design command area for the trial was taken as 6 ha to prevent overstressing the pumps (Figure 3).

TABLE 1. Borehole production test results from the school site.

	Units	August 2014[1]	July 2015[2]
Static water level	m	2.57	5.27
Pump depth	m	20	20
Maximum drawdown	m	0.18	1.37
Pump discharge	l/s	0.63	2.27
Well specific capacity	l/s/m	3.5	1.7
Well potential yield[3]	l/s	31.3	14.9

Notes: [1] Taken from DoI 2014.

[2] This study.

[3] Well potential yield = well specific capacity x acceptable drawdown. Acceptable drawdown was estimated to be 9 m from the lowest groundwater level during the year (6 m), the well depth (30 m) and the maximum pumping depth (20 m) considering a safety buffer (5 m).

Water Distribution System

Grundfos (model SP8) submersible pumps with a rated discharge of 2.2 liters/second at a 24 m head were installed in each borehole. The distribution system comprised of both primary and secondary pipes with diameters of 63 mm and 50 mm, respectively. The primary pipes connect the pumps to the storage tanks and convey water to the edge of the command area, whereas the secondary pipes are typically buried within the edge of the paddy fields to convey water directly to the fields. Flexible polyethylene (PE) pipes were used throughout due to their high resistance to ageing. A total of 11 gates were fitted along the western boundary of the command area. The irrigating farmers could, therefore, easily control the water flow and direction by closing or opening the gates. An elevated storage tank was initially incorporated into the design at the request of the farmers to help buffer the impacts of periodic power cuts, but was ultimately abandoned as it resulted in lower water pressure and flow through the system.

The system outflow was estimated at 4 liters/second, with the two pumps operating at the same time. Water pressure in the system could reach 3 to 4 bars, allowing for the use of sprinklers over an area of 800 m^2, or drip irrigation over more than 2,000 m^2 at one time. Opening only one gate at a time could achieve higher pressure and outflow. However, when combined used of the system is required, two gates could be opened at one time with outflow reduced by half (i.e., 2 liters/second), which is sufficient for surface irrigation practices (i.e., furrow).

Investment Cost

The total investment cost for the construction of the irrigation system at the school site is estimated to be USD 13,390 (LAK 109.8 million) or around USD 2,200/hectare (LAK 17.9 million/ha). The investment cost includes the cost of materials, equipment and labor (Table 2).

FIGURE 3. The irrigation system at the school site indicating the command area and monitoring equipment installed.

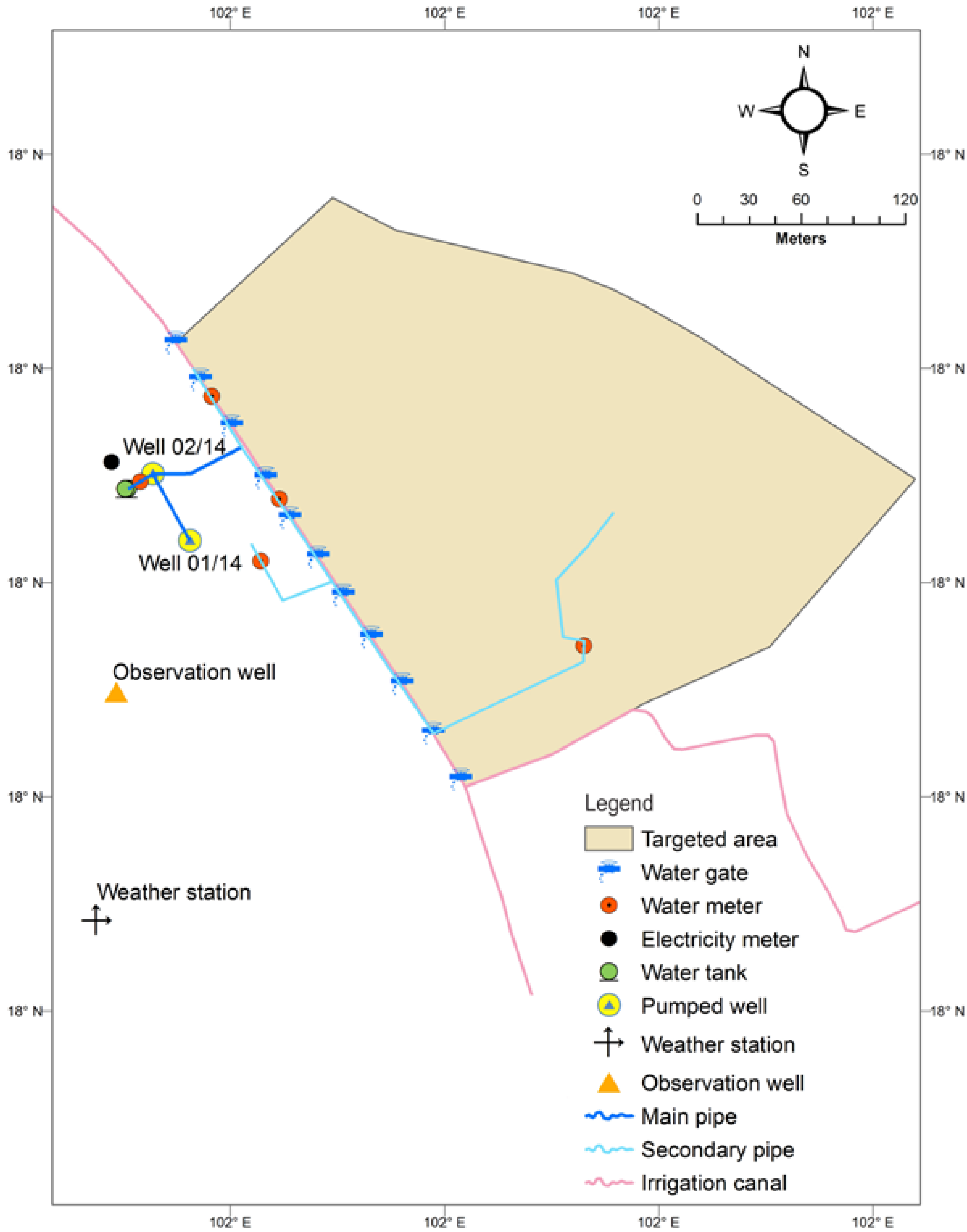


TABLE 2. Summary of the investment costs by item for the school site.

Description	Cost (LAK)	Cost (USD)
Drilling and testing (two boreholes)	32,800,000	4,024.54
Pumping equipment	20,082,100	2,464.06
Electricity grid extension	20,562,000	2,522.94
Water pipe network	14,692,860	1,802.80
Pump house	5,250,000	640.24
Drip irrigation system	9,880,000	1,204.88
Sprinkler irrigation system	2,074,000	252.93
Anti-ant and anti-termite treatment	4,460,000	543.90
Total	109,800,960	13,456.29

Note: The exchange rate used in this paper is USD 1 = LAK 8,150 (based on the Bank of the Lao PDR official exchange rate in November 2016; http://www.bol.gov.la/english/exchrate.html).

Establishment and Functioning of Groundwater User Group (GWUG)

Aims, Responsibilities and Principles of GWUG

The main objective of a Groundwater User Group (GWUG) is to enable farmers and members to participate effectively in the collective management of the groundwater irrigation system, and to avoid any unintended conflicts over water distribution. In a broader scale, GWUG should help to ensure the sustainable use and management of local groundwater resources.

A GWUG should follow a democratic, transparent organizational structure and functioning, especially in their financial management (Keoka 2005; IWMI and SIC ICWC 2003). In theory, a typical GWUG is responsible for the following:

- *Local groundwater resources management*: Groundwater is susceptible to overuse and pollution, which can adversely threaten continuity and sustainability of groundwater irrigation. It is necessary for GWUG to have a basic understanding of the resource potential, impact of groundwater extraction and potential threats so that they can engage in the planning of groundwater irrigation.
- *Irrigation management*: A GWUG is responsible for the planning and management of irrigation practices to ensure that there is adequate water for irrigation to all member farmers. Active involvement of GWUG is crucial in decision making to ensure profitable cultivation. Topics of interest include the method of water application (e.g., how, when and how much) and crop selection (e.g., what crops, when and how to grow).
- *Operation and maintenance*: This refers to the technical and organizational responsibility of GWUG to ensure sustainable operation of the groundwater irrigation system. Good operation and maintenance is essential for members to receive adequate water for irrigation in a timely and effective manner.
- *Financial management*: Financial sustainability is at the heart of GWUG functioning, and weak financial processes could weaken or lead to disintegration of GWUG. GWUG should ensure the financial viability of the groundwater irrigation system, which includes ensuring there are sufficient funds for conducting regular maintenance tasks.

- *Group management*: GWUG is responsible for overall functioning to ensure the above-mentioned tasks are carried out effectively. GWUG must resolve potential conflicts during operation and management of the groundwater irrigation system. Besides implementing routine tasks (organizing regular meetings, discussion about problems, conflict resolution), there should be a flexible planning process to address the opportunities (e.g., market, productivity gains, diversification of services beyond water management) and threats (e.g., higher energy price, droughts, decline in groundwater level, pest attack, labor shortages).

Formation of a GWUG should be inclusive in its representation and based on community needs rather than on predetermined, top-down decisions. GWUG, with agreement among participants, establishes a set of rules and regulations on water allocation, cost sharing, decision-making process and other operations. Effective and equitable water delivery, sound financial management, regular maintenance and mechanisms to prevent or resolve potential social conflicts are basic tenets for sustainable operation of the irrigation system (Keoka 2005; Ricks 2015).

Preliminary Community Assessment and Engagement

A bottom-up consultative approach was adopted by the project team throughout the study period. Engagement with the village community started in late 2012 by providing a brief overview about groundwater irrigation and the objective to establish the community irrigation trial in the village. The wider community, including farmers, and local authorities were consulted at that time and during all stages of development of the project and were involved in the design and construction of the system. Particular care was given to ensure that the Village Authority, Elders Association and Farmer Groups (i.e., Agricultural Production Group and Greenhouse Group) were fully consulted due to their standing and influence on agricultural development in the village. It is noteworthy to mention that all villagers were invited to join the GWUG and participate in the trial. Particular attention was given to understanding the local context and farmers' needs and expectations in relation to irrigated agriculture. As part of the larger project on agricultural water use in Lao PDR (ACIAR 2016), parallel investigations on farming systems and farmers' perceptions concerning groundwater at the household and village levels were also conducted in Ekxang and another nearby village (Suhardiman et al. 2016, Forthcoming). The insights from those investigations were drawn upon in this study.

Establishment of a GWUG

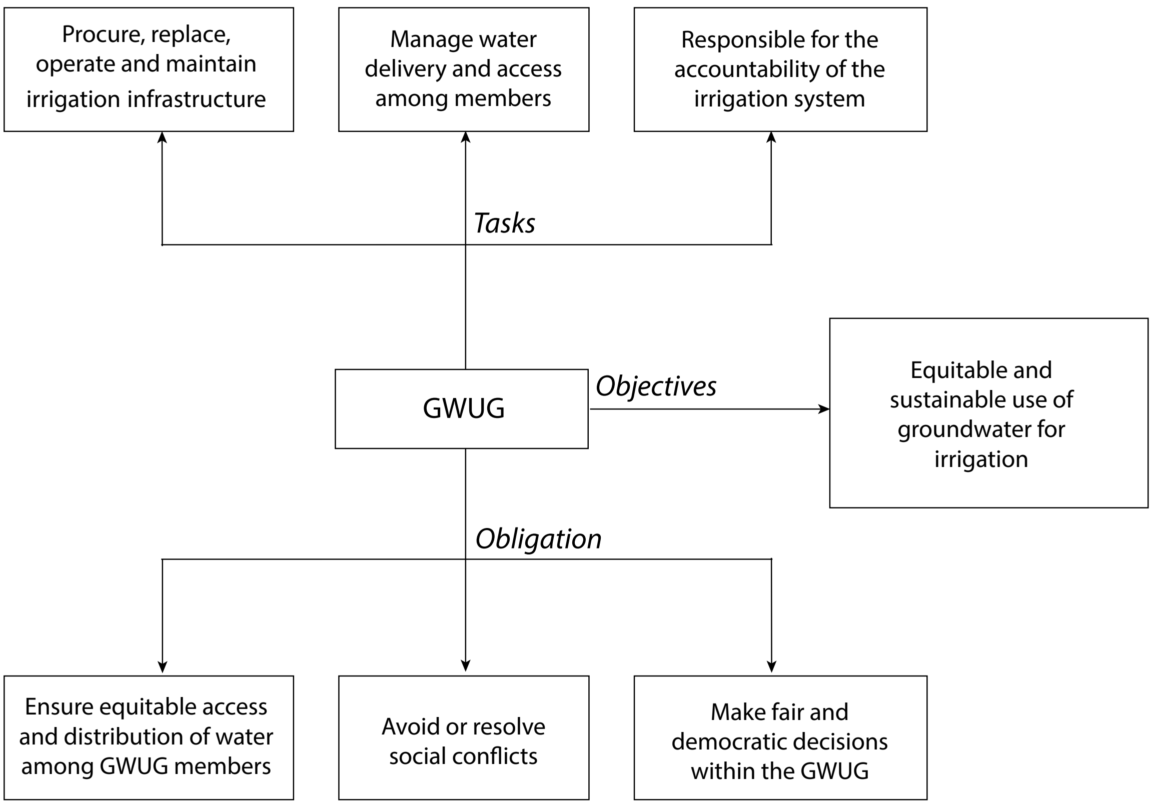
The Ekxang village GWUG was established as a self-governing institution to manage the groundwater irrigation system. Formalization of the GWUG followed the Department of Irrigation's legal and regulatory protocols regarding the formation of a Water Users Association (WUA)[1], which is founded on the "Decree on Articles of Associations for Irrigation - Water Users Association" (No. 0256/AF - March 1997) and the "Decree on Establishment and Operation of WUAs" (No. 1150/AF - June 2000). The formalization process was completed after 2 days of training with the village community covering the essential elements for building the required institutional structure and regulatory functions of the GWUG, such as (i) the aims of the GWUG, (ii) roles

[1] Although the establishment of a Groundwater User Group (GWUG) did not require as much institution building as a Water Users Association (WUA), national decrees on WUAs were used as a solid basis for the formation of the GWUG and the participatory approach applied.

and responsibilities of its members, and (iii) conflict management. A specific Terms of Reference (TOR) was also prepared with the particularities of GWUG functioning, and the associated roles and responsibilities of its members. This TOR followed a relatively flexible approach whereby adjustments in the institutional rules for the GWUG were agreed during discussions and trainings with the participating farmers. The established rules and regulations had to (i) match local needs and conditions, (ii) ensure that those affected by the rules can participate in modifying the rules, and (iii) be flexible enough to add or remove members if necessary, according to the needs and demands of the GWUG. The Ekxang GWUG was officially setup on May 29, 2015, and formally recognized under the authority and supervision of the DAFO Phonhong office, after the transfer of the irrigation system from the Department of Irrigation to the GWUG by following the "Decree on Full Transfer of Irrigation Systems to WUAs" (No: 1149/AF, June 2000).

Figure 4 illustrates the objectives, tasks and obligations of the Ekxang GWUG, and the institutional structure is presented in Table 3. The local community elected the head of the GWUG and two deputies. The roles and responsibilities of each position were approved by the members. The GWUG administration was represented by influential people in the village, such as the head and former head of the village, and retired Village Authority members (referred to as the 'Elders'). They played a key role in establishing the GWUG, which greatly outweighed any potential risk associated with 'elite capture'.

FIGURE 4. Objectives, tasks and obligations of the Ekxang GWUG.



Source: Adapted from IWMI and SIC ICWC 2003.

TABLE 3. Institutional structure of the GWUG, and roles and responsibilities of the members.

Position	Responsibilities
Head	• Overall coordination and management of the GWUG • Direct communication with the deputy heads and members • Appoints one of the deputies as a substitute in his/her absence • Economic management of the GWUG (i.e., collection of revenue to cover the water cost, payment for maintenance, etc.)
Deputy Head	• Overall responsibility for operation and management of the irrigation system (i.e., undertake repairs and maintenance operations jointly with members, etc.) • Intermediary role between the head and members • Assist the head in managing the GWUG
Members	• Use groundwater in an efficient manner based on the agreed rules and norms • Record the amount of water used • Participate in the maintenance tasks • Provide feedback to the deputies and the head
External support (non-financial)	• Overall coordination with the village, district and provincial officials • Provide guidance and support to the GWUG

Calculation of Irrigation Water Cost

After agreement with the GWUG, calculation of the cost of irrigation water was based on the amount of electricity consumed by operating pumps rather than a designated price based on the pumped volumes alone. Each individual farmer's irrigation water cost was the share of the monthly electricity bill corresponding to total water consumption over each monthly period. The electricity fee increases with electricity consumption based on the calculation system used by Electricité du Laos (EDL) for contracts with private individuals. The calculation model is detailed in Appendix 2, taking the month of April 2016 as an example. On average, the cost of water for irrigation was calculated to be USD 0.037/m^3 (LAK 302/m^3).

Mobilization of Farmers and Support to the GWUG

Prior to commencement of the first cultivation season, the project team made a concerted effort to disseminate information verbally throughout the village and through demonstration of the irrigation system capabilities to farmers. Particular efforts were made to encourage the poorer farmers in the community to participate. While the farmers showed a strong interest in the project during its establishment, the number of farmers involved in the first year of cultivation was modest and even less in the second year, as discussed later in this paper. From the earliest stages, it was recognized that farmers' lack of trust in the groundwater irrigation system, in terms of the cost of water for irrigation and perception of the risk regarding the resource capacity, was a major constraint to their engagement. As a response, the project team proposed to cover the pumping and maintenance costs during the first dry season of cultivation. There was no membership fee to join the GWUG and no additional fees to recover the investment costs. In return, farmers agreed to record their water use and provide relevant agricultural data (e.g., crop type, water use, yield, etc.).

In the second year of the trial, all financial support was withdrawn. The GWUG together with the help of the Village Head and project team attempted to mobilize the farmers from Ekxang village to participate in the project. The key findings from the first year and the likely range of benefits under the conditions applicable for the second year were explained in a clear and balanced way during a community meeting attended by the GWUG and other villagers in August 2016. In addition, the main findings up to that point were summarized in simple terms in the form of a leaflet (in Lao language), which was disseminated throughout the village and delivered by hand during informal discussions. These discussions usually occurred in the field since the trial preparation timing coincided with the wet-season harvest period.

During the first year of the trial, the project team provided some level of support to the GWUG, in terms of irrigation practices and water management. This largely involved access to water-saving technologies, whereby equipment for sprinkler and drip irrigation were provided free of charge, but in limited quantity, to interested farmers in the GWUG. The rationale for this was to improve farmer understanding on how these technologies reduce water consumption, labor, and the resultant improvements in system efficiency and profitability. Regular advice was provided to farmers on improving irrigation efficiency by the project's field officer. This was considered necessary as it was not possible to mobilize local extension support effectively due to lack of human and financial resources. Considering the limited support capacity that the project team could provide to the GWUG and the relatively innovative approach of the project for farmers, the project team decided to limit guidance on a broader range of farm management practices as this was beyond the scope of what could be effectively achieved.

In the second year of the trial, the support provided to the GWUG by the project team was substantially reduced. Advice was also provided by the Napok Agricultural Research Center and the National Agriculture and Forestry Research Institute, which provided seeds and advice for the cultivation of sweet corn and peanut.

DATA COLLECTION AND EVALUATION APPROACH

Monitoring

The project team and the GWUG members jointly monitored the groundwater irrigation system. The aim was to evaluate the technical and financial performance of the trial. Institutional and social arrangements associated with the GWUG were recorded during discussions and informal interviews held with the participating farmers. The monitoring approach and methods were largely similar in both years, but efforts made to collect data during the second dry season of operation were modest in comparison to the first season due to resource constraints. The environmental and agricultural data collected are summarized in Table 4, and the methods applied are described below.

Environmental Data

Climate

Meteorological data were gathered using an automatic weather station (Vantage Pro2 supplied by Davis Instruments) installed near the Ekxang village office, which is located approximately 400 m from the trial site (Figure 3). The station recorded temperature, rainfall, wind speed, and air humidity and pressure data on a half-hourly basis.

Groundwater levels

Groundwater level data were recorded in an observation well located on the school grounds approximately 100 m away from the two boreholes (Figure 3). This well was previously used for community domestic water supplies, but is no longer in use. Data was recorded on a two-hourly basis with a pressure transducer linked to an automatic data logger (DipperLog, supplied by Heron instruments Inc.).

Agricultural Data

The project team collected data on agricultural inputs, labor, yield and price information through focus group discussions, interviews and questionnaires.

Irrigation data

Individual-level data on water use and electricity consumption were calculated on a daily basis. Daily readings were taken from the four water meters installed in the field and the electricity meter installed on-site by each farmer, who was asked to record his individual water use.

TABLE 4. Environmental and agricultural data collected.

	Category	Data	Unit
Environmental	Climate	Temperature	°C
		Air humidity	%
		Wind speed	km/hour
		Rainfall	mm
		Air pressure	bar
	Groundwater	Groundwater level	m
Agricultural	Land preparation	Labor required	day
		Diesel consumption	liters
	Seed	Crop type	-
		Quantity	kg
	Fertilizer	*Organic type*:	
		Source (animal manure, rice-husk biochar, etc.)	-
		Quantity	kg, liters
		Chemical type:	
		N-P-K ratio	-
		Quantity	kg
	Pest and weed management	*Insecticides and herbicides*:	
		Effective agent (glyphosate, parathion, etc.)	-
		Quantity	liters
	Irrigation	Water use	m^3
		Electricity consumption	kW

Note: N – nitrogen, P – phosphorus, K – potassium.

Evaluation

Farm-level profitability, project-level financial viability and crop water balances were calculated for the first year of operation, and used to estimate the efficiency and economic viability of groundwater irrigation. In the second year of operation, the analysis was restricted to a farm-level profitability analysis due to reduced inputs from the project team and, therefore, data limitations. Details of all the methods applied are provided below.

Farm-level Profitability Analysis

The benefit of the project for participating farmers at the farm level was assessed in terms of profits generated. Profit was determined from the total production value of the harvested crops (i.e., gross income) and the total value of expenses incurred during production (i.e., variable, pumping and maintenance costs). The variable costs included the expenses related to land preparation (hired labor or equipment), planting material (e.g., seeds), fertilizers (both organic and inorganic), and chemicals (pesticides, insecticides, herbicides). Farmer's machinery investment cost (i.e., two-wheel tractor) was not taken into account since their usage at the trial scale was negligible compared to the lifetime of the asset. However, these costs should be considered for irrigation systems of a larger scale and more intensive use of agricultural machinery.

Project-level Financial Viability

A cost-benefit analysis was carried out to assess the financial performance of the irrigation system. Based on the field data collected from farmers in the first year of operation, the benefits correspond to the total gross income generated by farmers. The costs included the initial investment (as given in the section on investment cost), the total variable costs and pumping costs (based on field data collected throughout the first year of cultivation) as well as the maintenance and repair costs, and the replacement costs. Given the small size of the irrigation system and the high quality of the system components, acceptable annual maintenance and repair costs were estimated to be 1.5% of the investment cost (Savva and Frenken 2002). The replacement costs were estimated given the useful life of the irrigation system components (Kay and Hatcho 1992). The electrical pumps were predicted to last 10 years, and the sprinkler and drip heads need to be changed every 5 years, whereas the buried pipelines have a useful life of over 20 years.

Using a 12% discount rate and a 20-year life span, three indicators – net present value (NPV), benefit-cost ratio (BCR) and internal rate of return (IRR) – were used to evaluate the viability of the irrigation system, in order to forecast the financial performance in the long run and consider different scenarios to optimize the financial viability of the system in future years. The chosen discount rate of 12% is based on the interest rate that multilateral organizations typically charge for irrigation project investments (Savva and Frenken 2002).

Crop Water Balance Analysis

CROPWAT, a crop water balance model, was used to establish the water-use efficiency of the major crops cultivated during the trial (Doorenbos et al. 1979; Allen et al. 1998). Table A3.1 in Appendix 3 presents the list of inputs required by CROPWAT, their source and the outputs produced by the model. CROPWAT calculates the water losses through evaporation, crop transpiration, seepage and deep percolation. In addition, the efficiency of the irrigation schedule was computed as the proportion of gross irrigation water stored in the crop root zone.

CROPWAT was run for five of the crops selected from the trial cropping pattern - rice, watermelon, pumpkin, sweet corn and 'small vegetables'. 'Small vegetables' refers to a group of vegetables and herbs such as salad, morning glory and coriander. Snake gourd and sweet potato were not assessed due to a lack of crop information in the database of the Food and Agriculture Organization of the United Nations (FAO). Soil characteristics used in the model calculation are provided in Table A3.2 in Appendix 3.

Gross irrigation application rate refers to the amount of water supplied to the agricultural field, and was taken from the records provided by the GWUG. Net irrigation supply refers to the amount of water that reaches the root zone. It was calculated using the FAO irrigation application efficiency as follows: 60% for furrow, 75% for sprinkler and 90% for drip irrigation. Unfortunately, no soil moisture measurements were made to validate these assumptions. Irrigation application efficiency was set to 100% for paddy cultivation, since all water reaches the paddy area and hence the root zone.

RESULTS IN THE FIRST YEAR OF OPERATION

Socioeconomic Profile of Members

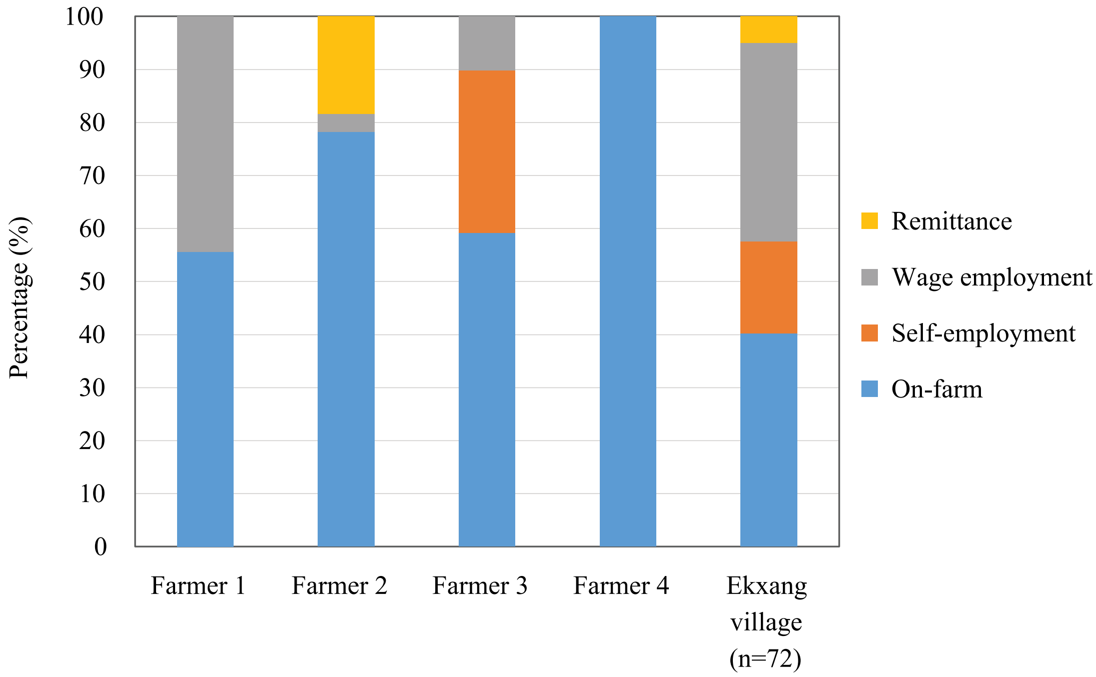
Four farmers were involved in the trial for the first year of cultivation, irrigating a total area of 1.52 ha. The socioeconomic profiles of these farmers are provided in Appendix 1, Table A1.2. They earn most or all of their income from on-farm activities; higher than the average for the village (Figure 5). Except for farmer 1, each farmer owns a two-wheel tractor. Only farmer 4 derives income from on-farm activities alone, whereas the others have diversified sources of income. Farmers 1 to 3 also sell their labor (wage employment) for agriculture-related tasks or civil work. Farmer 2 receives money from remittances and farmer 3 runs a small grocery shop in the village. Farmers 1 and 2 carry out vegetable gardening in their residential areas on plots of 600 m^2 and 400 m^2, respectively, whereas farmers 3 and 4 carry out commercial gardening on plots of 9,600 m^2 (0.96 ha) each. Farmer 3 cultivates watermelon as a monocrop on a 3-year rotational basis (i.e., the common practice for this type of crop).

All four farmers have land within the irrigation command area. All have experience in growing cash crops or dry-season rice, but often face water shortages. While there were initial doubts, they were attracted to the GWUG and finally became members due to the opportunity to have access to water in the dry season.

Operation and Maintenance of the Irrigation System

The first year of the trial commenced on December 22, 2015, and all agricultural activities concluded by May 5, 2016. The GWUG established an informal rotational irrigation schedule agreed upon by all four members. There was no need for major maintenance in the first year of the study. The maintenance that took place was in response to minor damage to pipes or electrical cables, and GWUG members fixed the irrigation system when they could. However, there were a few events that required support from the project.

FIGURE 5. Source of income of the four GWUG members compared with the average for the village.



Source: Survey conducted by the International Water Management Institute (IWMI) in 2016 with 72 of 236 (31%) households in Ekxang village, including the GWUG farmers.

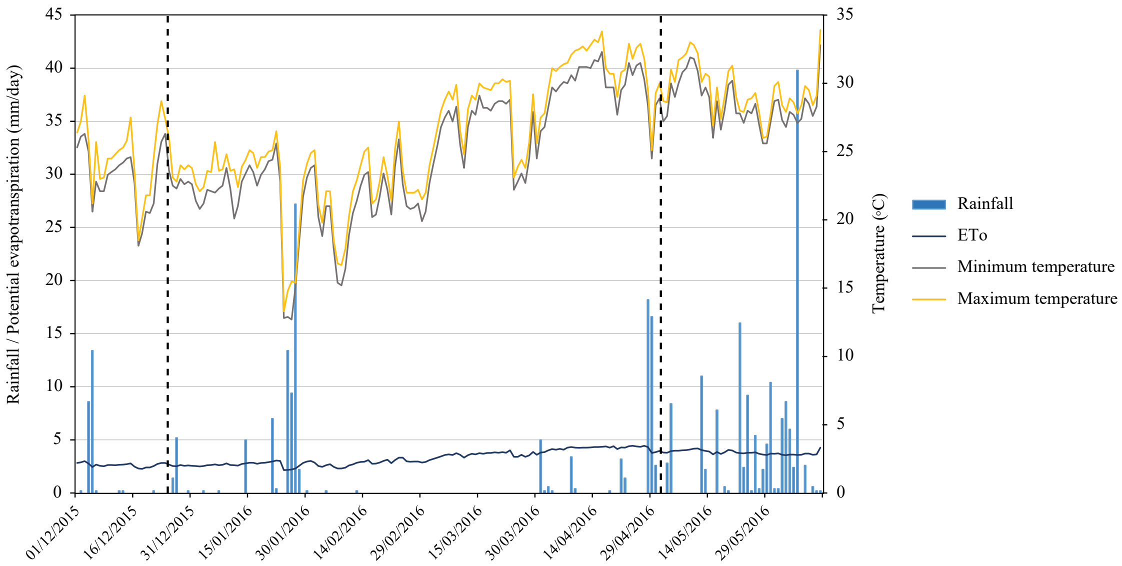
Climate During the 2015-2016 Dry Season

Figure 6 shows temperature, rainfall and evapotranspiration during the 2015/2016 dry season. Temperatures range from 13 °C in late January to 34 °C in April, the hottest month of the year. Rainfall events were sporadic and of low intensity, with most events under 15 mm. Intensification of rainfall in late May announced the onset of the monsoon season. Reference evapotranspiration (ETo) increased during the dry season, starting at about 2.5 mm/day in December and increasing to about 4.5 mm/day by late April.

Groundwater Level Response and Groundwater Use

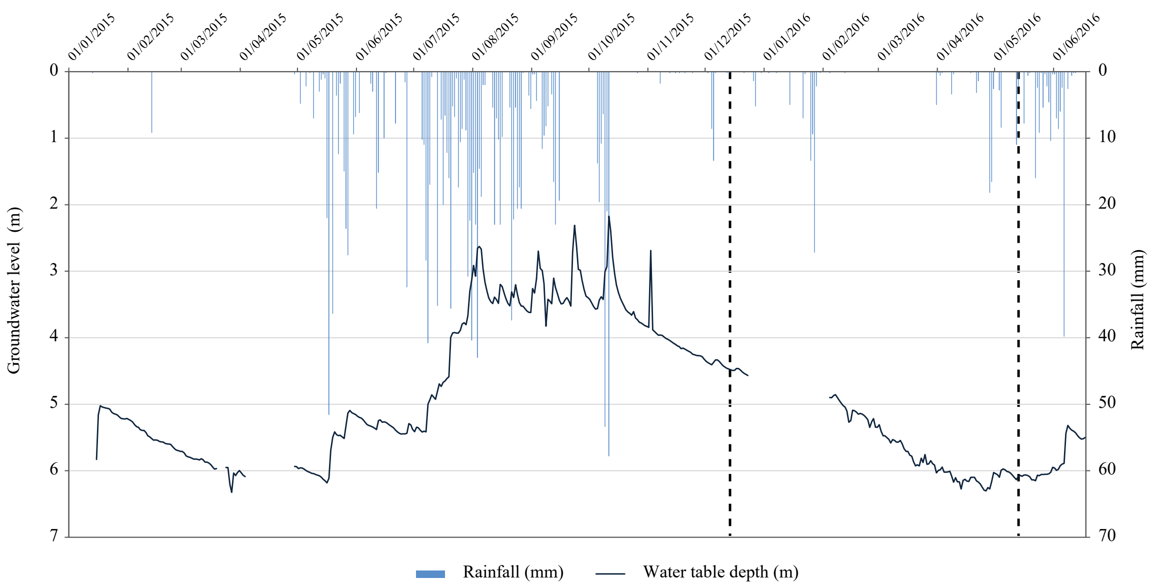
Figure 7 shows the groundwater levels recorded at the observation well situated within the school grounds. This shows the typical wet-season increase and dry-season decrease in groundwater levels, which is characteristic of the Vientiane Plain (ACIAR 2016). Overall, a 3 m change in the groundwater level was observed between the high levels in August-September 2015 and the low levels in April-May 2015. There is no evidence of an increase in the rate of decline for the dry-season groundwater recession over the trial period or in the maximum drawdown observed towards the end of the dry season (April 2016) compared to that of the previous year (April 2015). Total groundwater withdrawals for the trial period were 9,508 m^3 (see Table 9). In order to put the likely impact of the trial into perspective, this compares to 42,500 m^3 per annum for domestic consumption and an even larger 887,000 m^3 per annum for irrigation purposes estimated for the entire village (Serre 2013). Thus, the trial accounts for only around 1% of the total groundwater use in the village and was of an insufficient scale to have a major impact on the resource. If the trial was to be scaled up, ongoing groundwater monitoring by the GWUG with assistance from relevant authorities (i.e., Deparment of Irrigation [DoI] and Department of Water Resources [DWR]) would be essential to ensure the resource is not overexploited.

FIGURE 6. Agro-meteorological data during the 2015-2016 dry season (average daily value).



Note: The dashed lines indicate the start and end of dry-season cultivation.

FIGURE 7. Groundwater level fluctuations and corresponding rainfall patterns between January 2015 and June 2016.



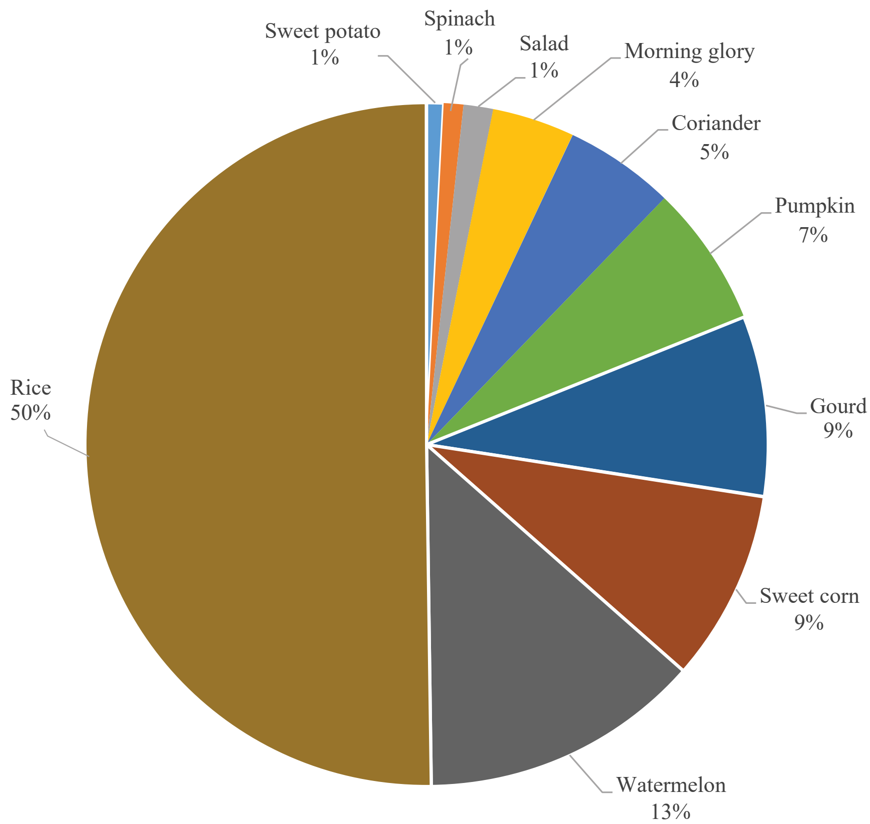
Note: The dashed lines indicate the start and end of dry-season cultivation.

Cropping Patterns and Strategies

The total area cultivated reached 1.52 ha, or around 25% of the total command area. Crop selection was made individually by the four farmers. Cash crops, including watermelon, snake gourd, sweet corn, pumpkin and sweet potato, were grown over 39% of the area cultivated (Figure 8). Additionally, they grew small vegetables and herbs such as coriander, morning glory, spinach and salad over 11% of the area as an extension to their home gardening. Rice cultivation represented 50% of the area.

The distribution of crops cultivated indicates very different cropping strategies among the farmers (Figure 9). Farmers 1, 3 and 4 saw the irrigation trial as a means to grow cash crops while farmer 2 saw it as a means to grow a second rice crop. Although the project team clearly explained that the irrigation system was not suited to dry-season paddy cultivation, rice cultivation was still pursued by farmer 2. Detailed cropping strategies for each farmer are provided in Figure A4 in Appendix 4.

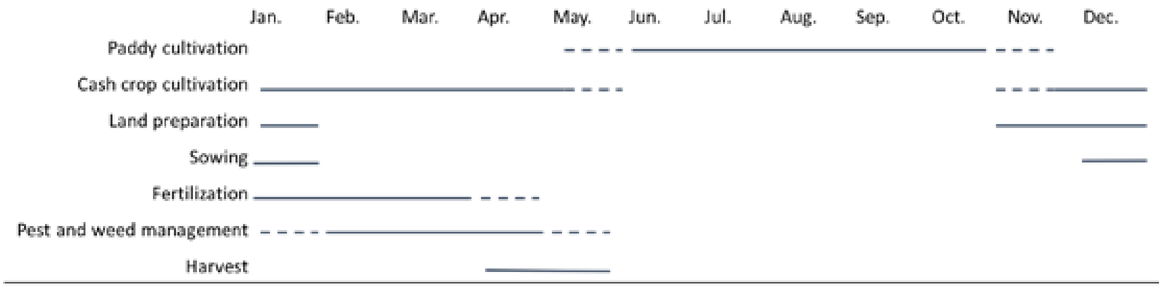
FIGURE 8. Overall cropping pattern in the first dry season.



Agricultural Practices

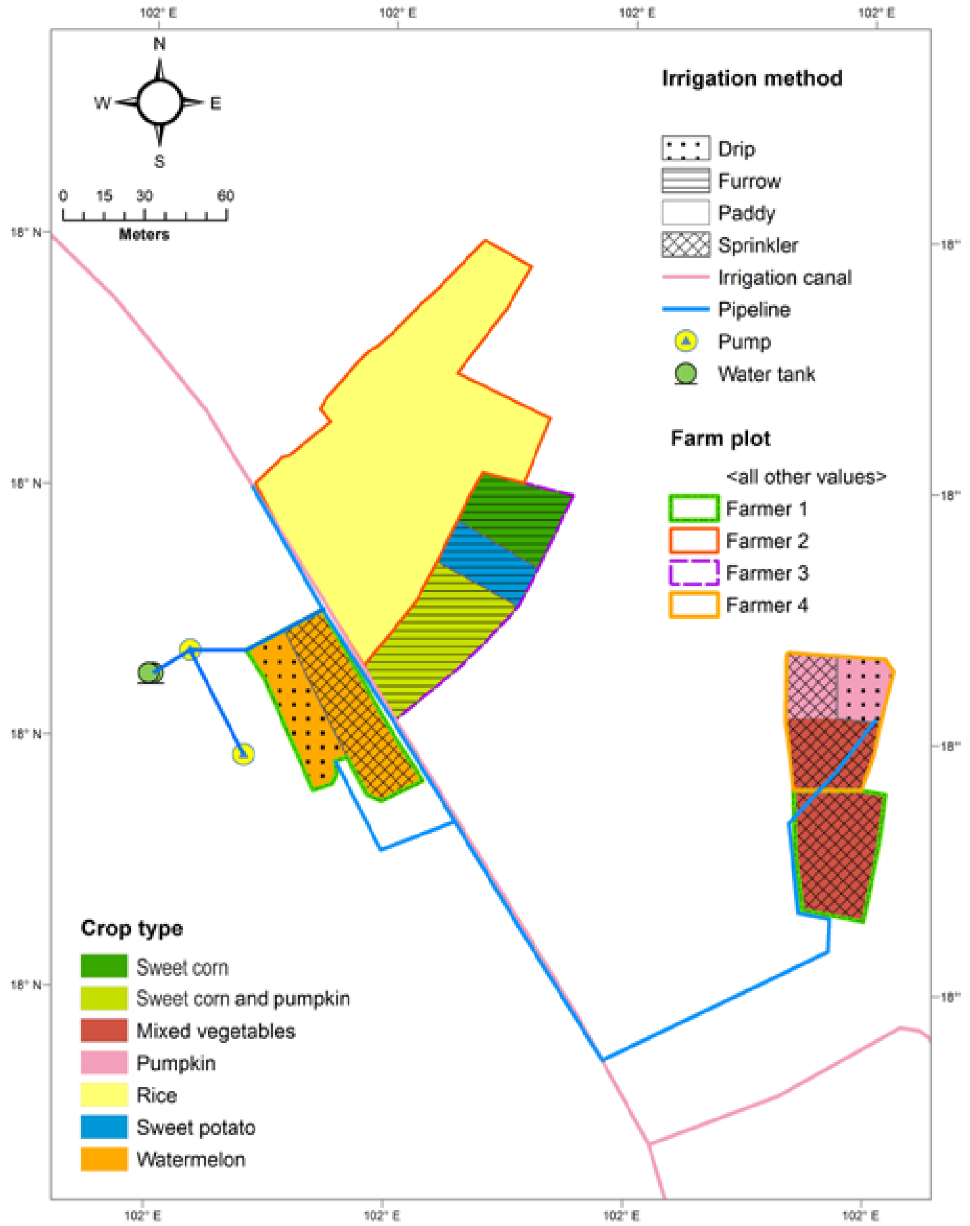
Dry-season cultivation started soon after the wet-season paddy cultivation ended over the period from October to November. The crop cycle, commencing with land preparation and proceeding through to harvest, followed standard local practices as shown in Table 5. The description of these practices and the related costs are presented below.

TABLE 5. Agricultural practices associated with wet- and dry-season cultivation.



Note: The dashed lines indicate the typical variation within the season.

FIGURE 9. Distribution of crop types cultivated by the four farmers in the first dry season. The methods of irrigation are also indicated.



Land preparation

Preparation of the land mainly consists of plowing and harrowing the field, and constructing fencing to protect crops from roaming cattle. Plowing is usually done with a two-wheel tractor (known locally as the "tok-tok") running on diesel (USD 0.8 or LAK 6,500 per liter). Depending on labor availability within the household, farmers could hire extra agricultural laborers and/or equipment to carry out the land preparation. In the Ekxang area, the current agricultural labor rate is about USD 8.6 (or LAK 70,000) per person per day. The irrigation furrows and cropping beds are usually prepared manually.

Sowing

Most sowing is done directly on site except in the case of salad, which is sown in a nursery. In-row spacing usually follows the international standard, but inter-row spacing is wider, bringing about a low crop density overall. Sowing density data are presented in Table A4 in Appendix 4.

Fertilization

Farmers use both organic and inorganic fertilizers. The latter was applied in the form of NPK fertilizer at a rate of 25-5-5 (USD 0.6 or LAK 5,000 per kg). Application rates varied from 14 kg/ha to more than 66 kg/ha. Different organic fertilizers were used at the trial site. Pig manure was applied to the plant at a rate of approximately 1 liter per 10 plants during crop growth. Additionally, a combination of both cow manure and rice-husk biochar were applied at 550 kg/ha and 5-7 tons/ha, respectively, during the sowing stage. Given the cost of chemical fertilizer, farmers preferentially opted to use on-farm residues. They apply both types of fertilizer directly to the root zone, which explains the low application rates. Organic fertilizer was not applied to paddy fields.

Pest and Weed Management

Weeding was mostly done manually, particularly for small vegetables and herbs. A variety of insecticides, including cypermethrin, lambda-cyhalothrin and methyl parathion, were used in both preventive and curative ways at a rate which did not exceed 1 liter/ha (100 ml = USD 1.8/LAK 15,000). There were no pest attacks with a significant impact on crop production. Herbicides were not applied in cultivation during the pilot trial.

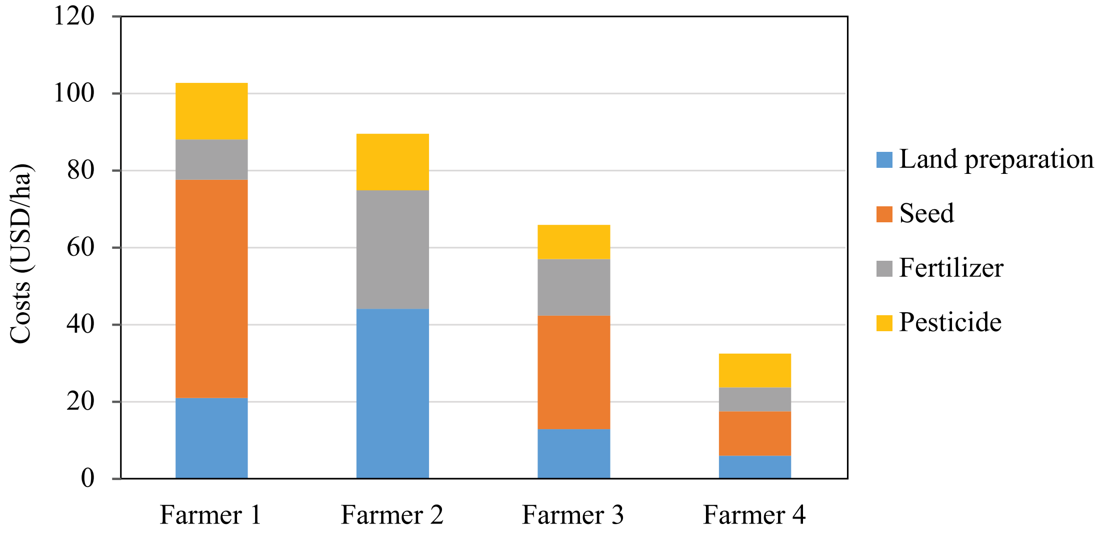
Harvest

Harvesting was done manually by the farmers. This activity can sometimes entail a need for additional labor, especially for crops such as rice. However, farmer 2 managed to harvest the entire paddy crop without hiring extra labor due to the small area cultivated and adequate labor availability within his household.

Variable Costs

Figure 10 illustrates the variable costs for each of the farmers. The differences in the cost are due to the specific farming practices of each farmer. The size of the area cultivated, and the availability of labor and equipment are factors that have a great influence on the total variable cost. The cost of seeds is also a significant proportion of agricultural variable costs (up to 50%) for the farmers who cultivated non-paddy crops (Figure 10). Only farmer 2, who used rice seeds from previous cultivations, did not purchase seeds. Chemical fertilizers accounted for a large portion of the total variable cost. Farmers also apply animal manure and rice-husk biochar, which normally do not incur a financial cost. However, in this case, farmer 1 purchased cow manure and farmer 3 purchased rice-husk biochar.

FIGURE 10. Variable costs for the four participating farmers.



Crop Water Management

Irrigation Methods

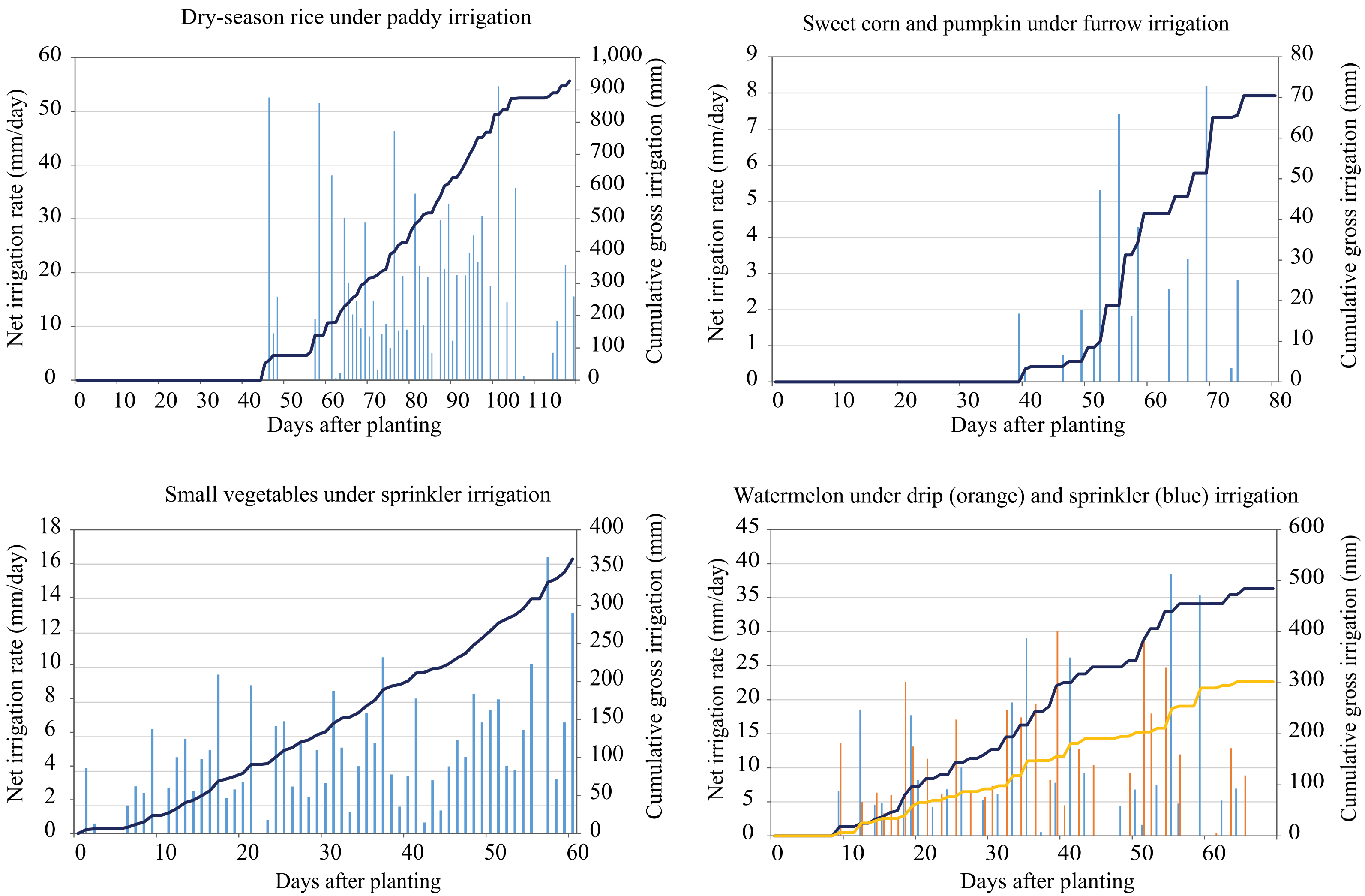
The paddy field, covering 50% of the cultivated area, received irrigation from the groundwater irrigation system as well as supplementary irrigation from surface water sources at the beginning of the dry season. Use of surface water, when available, was preferred over groundwater due to the lower irrigation cost. In non-paddy areas, sprinkler irrigation covered 23% of the cultivated area in the pilot site, while drip and furrow irrigation covered 11% and 17%, respectively, of the cultivated area. One sprinkler head could cover a surface of approximately 150 m^2 and has a design discharge capacity of 11 to 17 liters/minute. One drip head could deliver around 4 liters/hour[2].

Irrigation Timing and Rates

The timing and net application rate for each irrigation method and crop type are shown in Figure 11. Dry-season rice, sweet corn and pumpkin initially received irrigation from the local surface water source at the beginning of their growing period, while small vegetables and watermelon relied only on groundwater for irrigation water supply. Information on surface water application was not recorded. The on-site groundwater irrigation application rate and timing were used as inputs in the CROPWAT model to assess the irrigation efficiency.

[2] More information on drip and sprinkler irrigation systems in the region is available from Irrigation Technology Co. Ltd. (http://www.itec.co.th)

FIGURE 11. Groundwater irrigation timing and net application rate for each irrigation method and crop type.



Note: Dry-season rice, sweet corn and pumpkin were initially irrigated with surface water at unknown rates and, therefore, not taken into account.

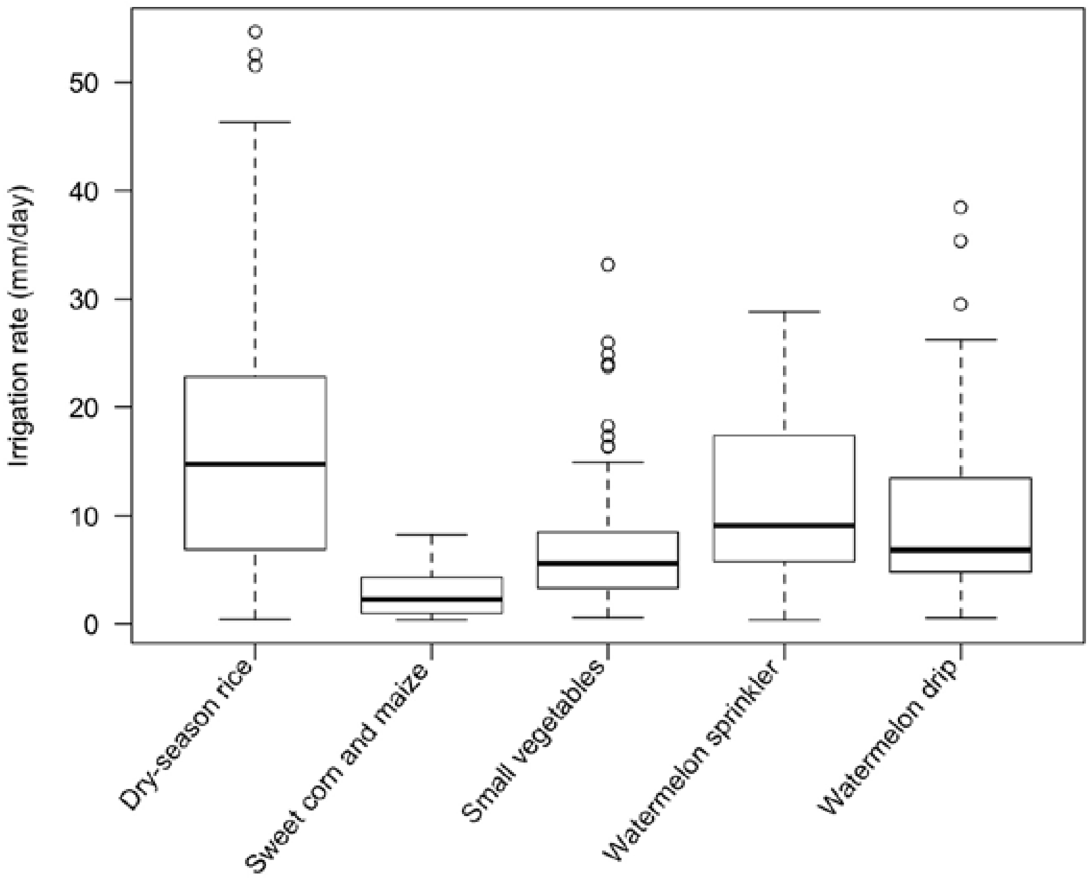
When focusing on the irrigation frequencies and rate (Table 6; Figure 12), dry-season rice was irrigated with groundwater every 1 or 2 days at a rate of 14.7 mm per application. Small vegetables received a rate of 5.6 mm every day. Sweet corn and pumpkin were irrigated every 3 to 4 days at a rate of 2.3 mm per application. Watermelon was typically irrigated every 2 or 3 days and received 9.1 mm and 6.8 mm under sprinkler and drip irrigation[3], respectively.

TABLE 6. Summary of irrigation frequencies for different methods and crops (average values given).

Crops	Dry-season rice	Sweet corn and pumpkin	Small vegetables	Watermelon	Watermelon
Irrigation method	Paddy	Furrow	Sprinkler	Sprinkler	Drip
Frequency	1-2 days	3-4 days	daily	2-3 days	2-3 days

Note: Information for watermelon refers to the period when a disctinction was made between drip and sprinkler irrigation.

FIGURE 12. Variations of irrigation rate per crop and irrigation method. The dark horizontal line within each box plot represents the median value.



[3] During the first 10 days of the trial, the distinction between drip and sprinkler irrigation rates was not properly recorded for watermelon, which limited our understanding of farmers' irrigation practices. However, during this germinating period, watermelon received water every day at an average rate of 6 mm. Information in the text refers to the period when a disctinction was made between drip and sprinkler irrigation.

Crop Water Requirement

Crop water and irrigation requirement, and the amount of rainfall received during the growing period are given in Table 7. Small vegetables have the lowest crop water requirement of 146 mm in total. This estimation was calculated for small vegetables with a growing cycle of 60 days and, therefore, it overestimates the water requirement of vegetables with a shorter growing cycle (i.e., < 60 days). Sweet corn and pumpkin had a similar water requirement of approximately 160 mm. Watermelon, with 191 mm, and rice, with a far higher 420 mm, were the two crops with the highest crop water requirements. Rainfall provided some of the crop water requirements, with all the crops receiving around 50 mm during their cultivation period except for rice, which received around 100 mm due to its longer cultivation period.

TABLE 7. Crop characteristics, and water and irrigation requirement for small vegetables, watermelon, sweet corn, pumpkin and rice.

	Planting date	Growth stages	Period (days)	Kc	ETc (mm/day)	∑ ETc[5] (mm)	Eff.[6] Rain (mm)	IR[7] (mm)
Small vegetables	12-Jan-16	Ini.[1]	0-10	0.7	1.95	17.5	3.6	13.5
		Dev.[2]	10-30	0.80 ± 0.1	2.1 ± 0.1	44.1	47.7	22
		Mid.[3]	30-50	1.05	2.75 ± 0.05	49.3	-	49.3
		Lat.[4]	50-60	0.85 ± 0.05	2.90 ± 0.05	35.3	-	35.3
		TOTAL				**146.2**	**51.3**	**120.1**
Watermelon	1-Mar-16	Ini.[1]	0-10	0.4	1.34	13.4	-	13.4
		Dev.[2]	10-30	0.65 ± 0.1	2.2 ± 0.05	49.8	4	45.8
		Mid.[3]	30-50	0.80 ± 0.05	3.0 ± 0.5	71.6	3.8	67.7
		Lat.[4]	50-70	0.75 ± 0.1	3.2 ± 0.5	56	41.8	14.2
		TOTAL				**190.8**	**49.6**	**141.1**
Sweet corn	7-Jan-16	Ini.[1]	0-10	0.3	0.8	8.3	4	4.2
		Dev.[2]	10-30	0.50 ± 0.15	1.30 ± 0.4	36.1	47.7	21.4
		Mid.[3]	30-55	0.96 ± 0.02	2.70 ± 0.2	67.1	-	67.1
		Lat.[4]	55-75	0.60 ± 0.25	2.10 ± 0.7	50.7	2.2	48.7
		TOTAL				**162.2**	**53.9**	**141.4**
Pumpkin	7-Jan-16	Ini.[1]	0-10	0.4	1.11	11.1	4	7.1
		Dev.[2]	10-30	0.50 ± 0.1	1.40 ± 0.15	35.1	47.7	19.4
		Mid.[3]	30-60	0.80 ± 0.05	2.60 ± 0.35	74	-	74
		Lat.[4]	60-80	0.60 ± 0.2	2.40 ± 0.6	45.8	4	41.8
		TOTAL				**166**	**55.7**	**142.3**
Dry-season rice[8]	26-Dec-16	Ini.[1]	0-20	1.1	3.04	62.5	51.7	26.4
		Dev.[2]	20-50	10.5 ± 0.02	3.0 ± 0.15	83	-	83
		Mid.[3]	50-100	1.02	3.90 ± 0.5	197.6	7.8	189.8
		Lat.[4]	100-200	0.95 ± 0.3	3.9 ± 0.3	77.1	41.8	34.5
		TOTAL				**420.2**	**101.3**	**333.7**

Notes: [1] Ini. - initial phase; [2] Dev. - development phase; [3] Mid. - middle phase; [4] Lat. - late phase; [5] ∑ - cumulative; [6] Eff. - Effective; [7] IR - Irrigation requirement; [8] no nursery stage since rice was sown by broadcasting the seeds directly on the field; Kc - crop coefficient; ETc - actual crop evapotranspiration.

Irrigation Efficiency

Table 8 shows the result of the water balance and irrigation efficiency for the crops cultivated at the trial. With 930 mm used over the irrigation period[4], paddy cultivation consumed the most water. However, it was estimated that more than 700 mm was lost through deep percolation. Irrigation schedule efficiency reflects the capacity of the irrigation schedule to provide sufficient water to the crop in quantity and time. For paddy cultivation, irrigation schedule efficiency was estimated at 95%, which illustrates the relatively appropriate schedule to compensate for both crop evapotranspiration and deep percolation. However, irrigation yield reduction calculated by the CROPWAT model underestimates the real yield losses observed in the field (see section *Crop Yield*). This suggests an inaccurate estimation of the percolation rate or its potential increase by the formation of soil cracks created under non-flooded conditions, resulting in reduced access to water for the rice crop.

Surprisingly, areas under sprinkler and drip irrigation received a lot of water, ranging from 350 to 480 mm, resulting in large irrigation losses ranging from 100 mm to 220 mm through runoff and percolation. With such inappropriate irrigation management, it is not surprising that the irrigation efficiency for both methods (drip and sprinkler) was not higher than 55%. Areas under furrow irrigation received the least irrigation water, with 75 mm over the growing period, and irrigation efficiency reaches 95% under this irrigation method. The CROPWAT model estimated smaller losses for pumpkin and sweet corn, and no yield losses for small vegetables, which matches with the field data (see section *Crop Yield*). Lack of experience with sprinkler and drip equipment, compounded by the waiver provided on the pumping costs, probably led the farmers to over-irrigate rather than under-irrigate. Since furrow irrigation generally relied on the farmers being present to undertake the activity manually, the water application rate was less.

TABLE 8. Crop water balance and irrigation efficiency determined by the CROPWAT model.

Crop type	Watermelon		Small vegetables	Pumpkin/Sweet corn	Paddy rice
Irrigation type	Sprinkler	Drip	Sprinkler	Furrow	Paddy
Irrigation period (days)	0-70	0-70	0-60	40-80	45-120
Field application efficiency (%)	75	90	75	60	100
Total gross irrigation supply (mm)	482	357	356	75	930
Total net irrigation supply (mm)	362	305	247	45 / 45	930
Total crop water requirement (mm)	190	190	146.2	89 / 84	240
Effective rainfall (mm)	31.2	34.3	2.1	24.1 / 29.5	71.2
Total irrigation losses (mm)	213.4	159.8	112	2.3 / 1.8	764.2
Actual water use by crop (mm)	187.4	187.1	143.5	80.5 / 86	162.2
Irrigation schedule efficiency (%)[1]	41.1	47.6	54.7	94.9 / 95.9	95.3
Yield losses due to water stress (%)	0.5	0.6	0	8.5 / 7.4	15.4

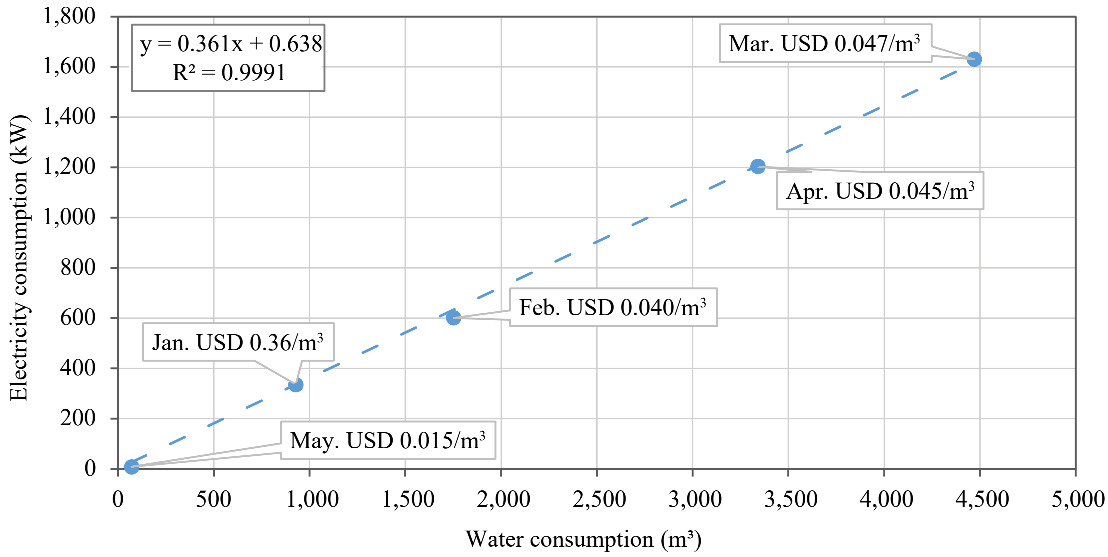
Note: [1] Irrigation schedule efficiency = proportion of gross irrigation stored in the root zone.

[4] This refers to groundwater irrigation only, recognizing that initial irrigation was from surface water.

Irrigation Water Cost

Throughout the cultivation period, the electricity used to lift groundwater during the dry season was found to be approximately constant (Figure 13). The price of water was USD 0.037/m^3 (LAK 302/m^3) on average and ranged from USD 0.015/m^3 to USD 0.047/m^3 (LAK 122/m^3 to LAK 383/m^3) over the cultivation period. Monthly variability is explained by the fluctuations in farmers' water consumption across the dry season, which are presented hereafter. The price for water pumped in May (USD 0.015/m^3) was the lowest due to the use of surface water and the smaller irrigated area (Figure 14). Gradual increase in the cost of water in the subsequent months (USD 0.047/m^3 or LAK 383/m^3 in March, and USD 0.045/m^3 or LAK 367/m^3 in April) was due to the increase in the amount of groundwater being pumped in the peak dry period and mid- to late growing season.

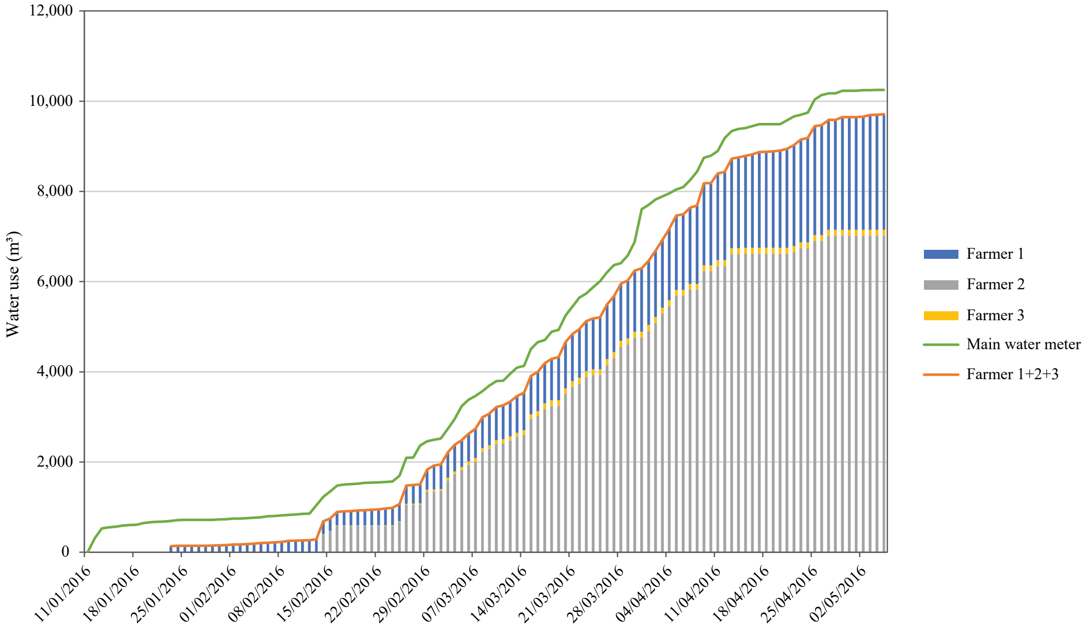
FIGURE 13. Evolution of electricity consumption according to water consumption. The type of electricity contract was chosen during the design phase. Other contracts for irrigation purposes proposed by EDL uses different calculation models.



Farmers' Water Consumption and Irrigation Cost

Over the total of 120 days of cultivation, the total volume of water pumped was 9,508 m^3 (Table 9). Cumulative water consumption per farmer and for the entire irrigation system over the cultivation period is displayed in Figure 14. Total water consumption and the related cost per farmer are displayed in Table 9. Besides irrigation, an additional 117.7 m^3 of water were supplied for the school toilets.

FIGURE 14. Water consumption by individual farmer.[1, 2]



Notes: [1] The offset of 600 m^3 between the main water meter and the cumulative water use of the three farmers is due to individual water meters being installed in the field after the farmers started cultivating.

[2] The gap between the two curves between the 31st of March and the 4th of April shows an abnormal error due to an incorrect entry of the reading on the main water meter value which farmer 1 corrected afterwards.

Farmer 1 pumped 2,340 m^3 of water to cultivate two separate plots of mixed crops using water-saving technologies (drip and sprinkler), which represents 25% of the total consumption. Farmer 2 pumped the largest volume of water (7,020 m^3), which represents 74% of the total consumption while cultivating 50% of the total area. This relatively large proportion is due to the high water requirement for rice cultivation. Moreover, farmer 2 only partially relied on groundwater, and relied mostly on surface water until it ran dry (end of February). This explains the sudden increase observed on the water consumption curve after the first month and a half of cultivation, when farmer 2 became dependent on groundwater to irrigate his paddy field. Farmer 3 only pumped 128 m^3 of water to cultivate one plot of mixed crops using furrow irrigation, which represents 14% of the total area. Farmer 4 used only 20 m^3 of water as he disengaged from the trial at a very early stage and stopped cultivating his plot. After the disengagement, farmer 1 tried to maintain the field of farmer 4, although irrigation was somewhat erratic. Although data for farmer 4 does not appear in Figure 14, it was still used in the analysis.

TABLE 9. Water use and the cost to each farmer.

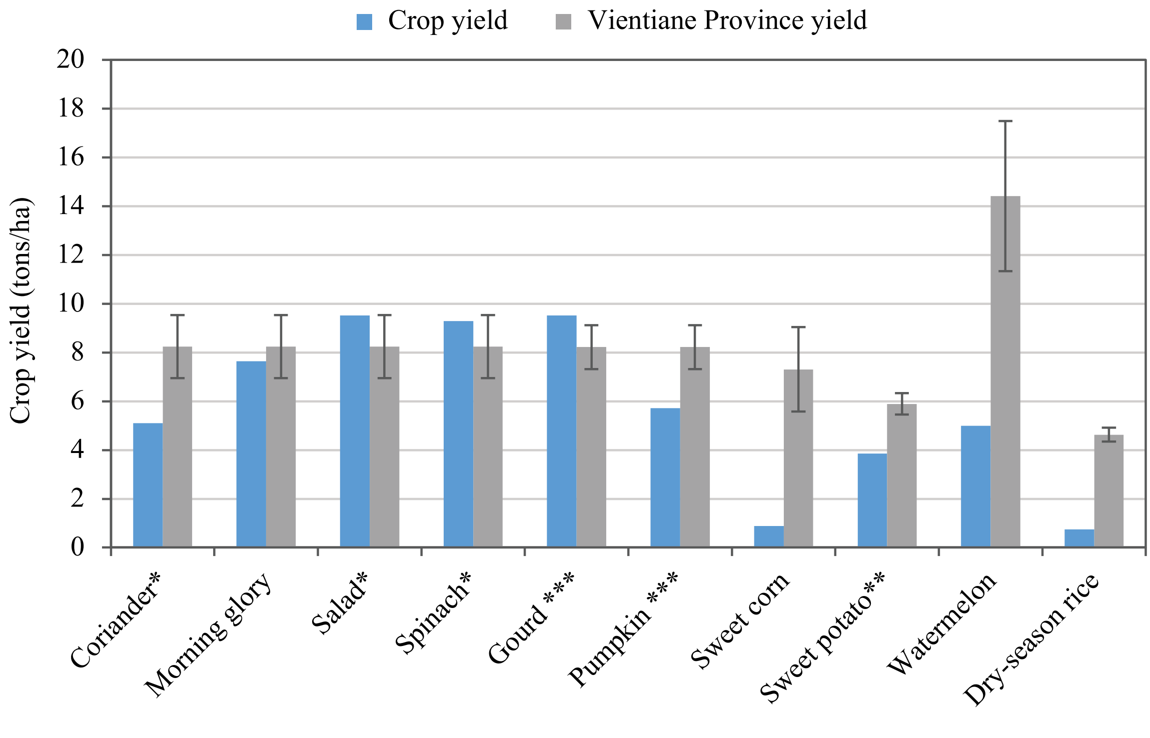
	Type of crop	Total water consumption (m^3)	Average pumping duration (hours:minutes)	Period between pumping (day)	Water cost USD / LAK
Farmer 1	Small vegetables, watermelon	2,340	1:38	1-3	110.5 / 900,600
Farmer 2	Rice	7,020	7:35	1-2	317.8 / 2,600,000
Farmer 3	Sweet corn, pumpkin, sweet potato	128	0:36	3-4	5.1 / 41,600
Farmer 4	Small vegetables, pumpkin	20	-		0.9 / 7,500

Agricultural Production

Crop Yield

Figure 15 shows the crop yields from the trial. Comparisons of average yield data were made for Vientiane Province from 2012-2014[5]. When provincial yield was not available for an individual crop, the yield of the closest crop category was used instead (i.e., vegetables, leafy stem vegetables, and roots and tubers). Yields obtained for morning glory, gourd, salad, spinach and sweet potato were of a similar range to the average for the province. Coriander was not harvested completely in some parts of the field since the market price dropped too low, and this could possibly explain the low yield observed in Figure 15. Sweet corn, watermelon and rice yields were all very low compared to the provincial average values. The agronomic practices of individual farmers, such as low sowing density, poor weed management or early harvest before the onset of the wet season, were likely responsible for the lower yields of these crops. In the case of the low rice yield, an adequate amount of water was not applied by the farmer mostly due to the limited water outflow rate, which implies very long irrigation duration and thus high irrigation cost. While these deficiencies are likely to be typical for the first year of a pilot trial, they also suggest that farmers could improve yield in subsequent years after becoming more adept to groundwater irrigation and related agronomic practices.

FIGURE 15. Crop yields from the trial compared with average yields for Vientiane Province.



Source for provincial data: Agricultural Statistics Yearbook 2012-2014[5].
Note: Crop categories used: * - leafy stem vegetables; ** - Roots and tubers; *** - Vegetables.

[5] Lao Census of Agriculture. 2012. Agricultural Statistics Yearbook. Agricultural Census Office, Department of Planning, Ministry of Agriculture and Forestry.

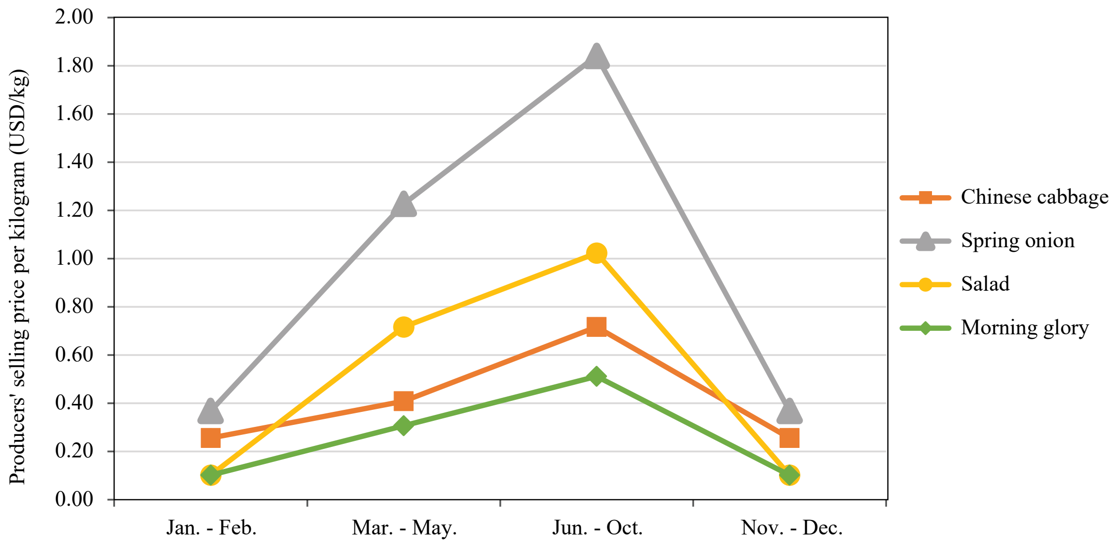
Lao Census of Agriculture. 2013. Agricultural Statistics Yearbook. Agricultural Census Office, Department of Planning, Ministry of Agriculture and Forestry.

Lao Census of Agriculture. 2014. Agricultural Statistics Yearbook. Agricultural Census Office, Department of Planning, Ministry of Agriculture and Forestry.

Marketing of Produce

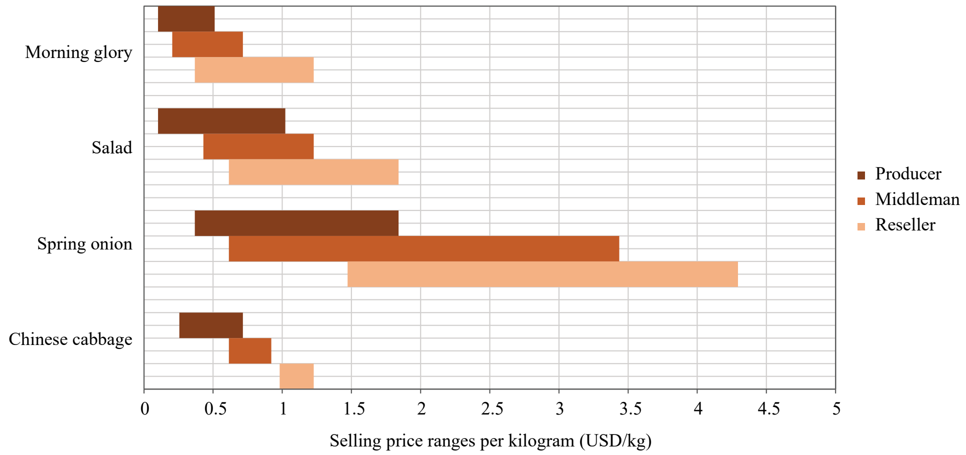
The most common method of selling produce in the village is to sell directly to middlemen (i.e., local traders) and less frequently to the local market, where prices and demand are low due to the large number of producers. Middlemen do not only originate from Ekxang village but also from other areas, and either directly sell the products to villagers (from the back of their truck on the roadside) or to retailers who have a stall at a market (i.e., in towns and cities such as Lak 52, Vientiane Capital, etc.). Middlemen play an intermediary role between producers (i.e., farmers) and consumers. Volatility of market prices is very high throughout the year owing to the high fluctuation in supply and more or less constant market demand for a particular crop type, which leads to a tendency for the market to be saturated rapidly for some crops while deficient for others. The lack of coordination between individual producers on the amount of production and supply, imports from neighboring Thailand, and most importantly bargaining by middlemen at the time of harvest have a significant influence on farmers' revenue. Figure 16 shows the evolution of prices for small vegetables and herbs over the year 2016. Prices for any particular crop can vary from threefold to tenfold over the year. Prices are highest at the end of the rainy season when most lowland areas are used for paddy cultivation and there is a decrease in the supply of non-paddy crops. In the dry season, producers' selling prices dramatically fall. It is noteworthy that for short periods around special events (e.g., Lao New Year in April), prices can also reach the levels during the wet season. The price volatility at the producers' level can also be seen at the levels of the middlemen and market resellers, generally with wider ranges (Figure 17).

FIGURE 16. Evolution of producers' selling prices for small vegetables and herbs.



Source: Authors' survey (April 2016).

FIGURE 17. Range of selling prices by producers, middlemen and market resellers.

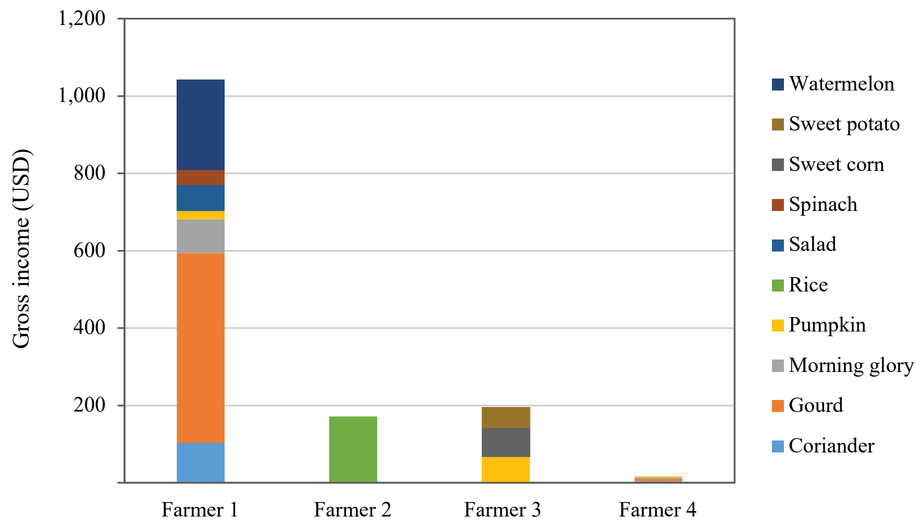


Source: Authors' survey (April 2016).

Revenue

Farmers' gross income was based on harvested quantities and the selling prices for their agricultural products at the time of harvest (Figure 18). There are large differences in the value of production between farmers. Details of harvested quantities and selling prices per crop, and gross income for each farmer are presented in Appendix 5. As the farmers started to cultivate and harvest most crops at a similar time, volatility in the selling prices equally affected their revenue. Farmer 1, who cultivated a diverse range of crops including both cash crops and small vegetables, generated the highest revenue, especially thanks to gourd and watermelon sales, which represent almost 70% of his total revenue. Farmer 3, who only cultivated cash crops but had very low yields, generated much less profit than farmer 1, even relative to the cultivated area. Farmer 2 only cultivated paddy rice and harvested much less than he could have expected, because the system could not provide sufficient water at the required time (see section *Discussion*). In addition to low crop yield, the selling price for rice is also among the lowest at USD 0.31/kg (LAK 2,500/kg).

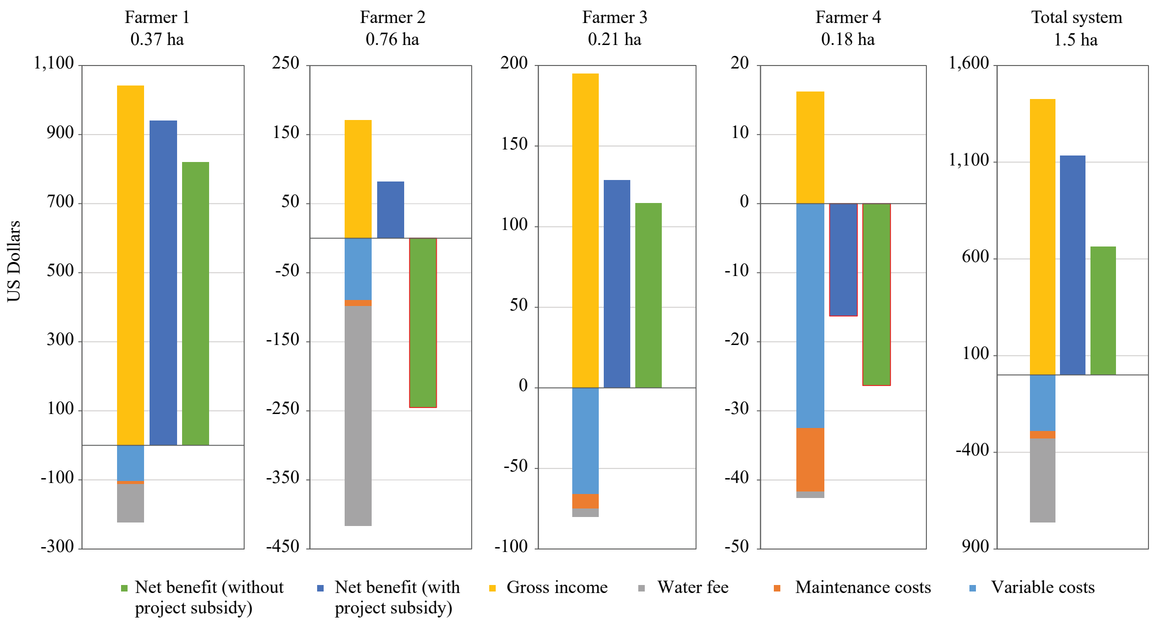
FIGURE 18. Farmer-wise gross incomes for different crops (USD).



Farm-level Profitability Analysis

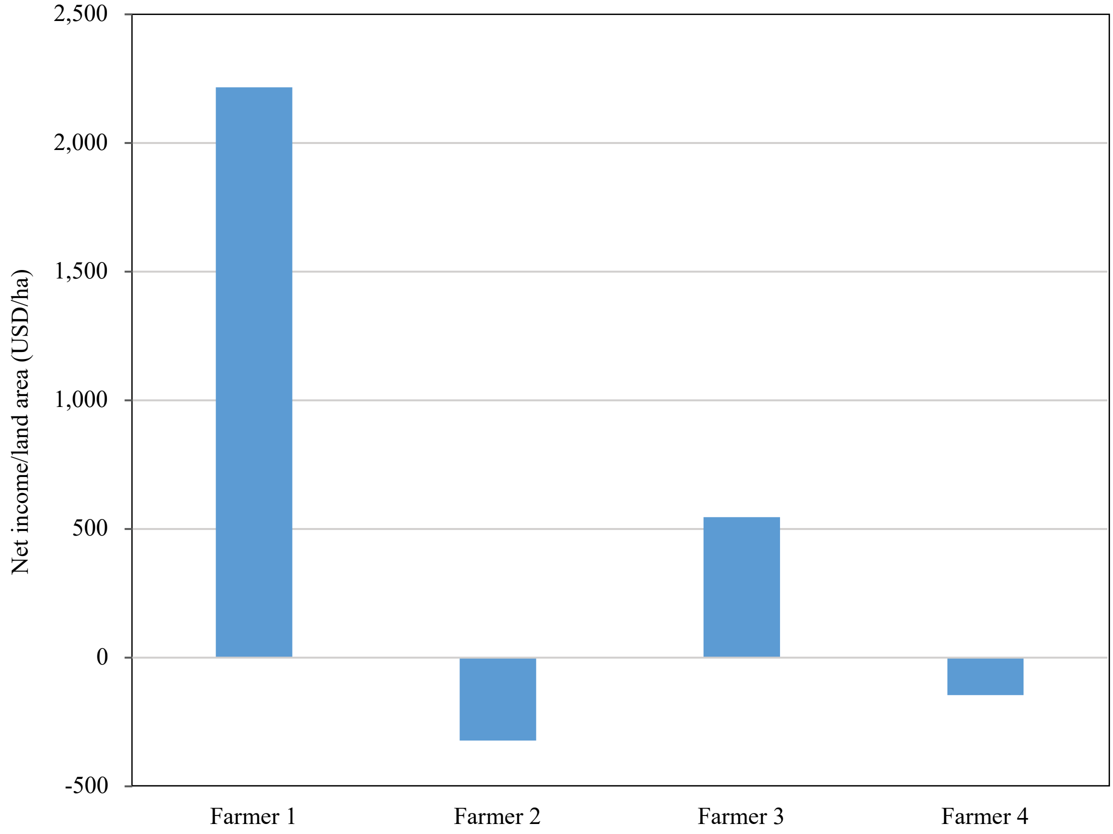
At the end of the cultivation period, the four farmers also achieved very different results in terms of profitability (Figure 19). Net profits were calculated for each farmer with and without the project subsidies (i.e., pumping and maintenance costs). At the system level, the four farmers generated higher incomes in both situations - with the project subsidy and without the project subsidy. Farmers 1 and 3 generated profits in both cases. Farmer 2 only derived benefits from paddy cultivation "with the project subsidy". Indeed, the low harvest would not have enabled him to cover the pumping costs for the season. The quantity of harvest was too low for farmer 4 to generate net benefits even with project subsidies. Naturally, farmers that engaged in mixed cropping had higher net incomes per unit area of cultivated land (Figure 20). Crop-wise analysis could not be realized due to the absence of crop-specific data.

FIGURE 19. Cost-benefit analysis per farmer with and without the project subsidy.



The financial results for the first year of the trial presented in this section show that the benefits were greater than the costs for farmers 1 and 3. It is clear that profitability of the system was highly dependent on the type of crop cultivated. As a consequence, calculation of the indicators reveals that, if the crops cultivated were to remain the same, the system would not be viable even with the project subsidies as long as farmers continue to grow rice (Table 10). In this situation, it would not be worth the investment unless farmers were convinced to forego the cultivation of dry-season rice and focus on cultivating cash crops that would generate higher incomes while requiring lower amounts of water.

FIGURE 20. Farmer-wise net incomes (without subsidies) per land area (USD/ha).



Considering scenario 1 where five farmers cultivated cash crops without any subsidy and following the same cropping pattern as farmer 1, the system would be financially viable with regard to the three indicators (i.e., Net Present Value, Benefit-Cost Ratio and Internal Rate of Return) (Table 10). Financial viability is further improved in scenario 2 assuming full adoption of the system (cultivated area of 6 ha), where half of the area would be cultivated by farmers following the same practices as farmer 1 (good performance) and the other half would be cultivated by farmers following the same practices as farmer 3 (lower performance).

TABLE 10. Financial viability of the system for different scenarios.

	Unit	First year data	Scenario 1 (partial adoption)	Scenario 2 (full adoption)
Cultivated area	ha	1.5	1.5	6
Cultivation period	day	120	120	120
Project period	year	20	20	20
Discount factor	%	12%	12%	12%
Net Present Value	USD	-5,569	13,185	42,171
Benefit-Cost Ratio	#	0.63	1.61	2.28
Internal Rate of Return	%	-8%	15%	45%

RESULTS IN THE SECOND YEAR OF OPERATION

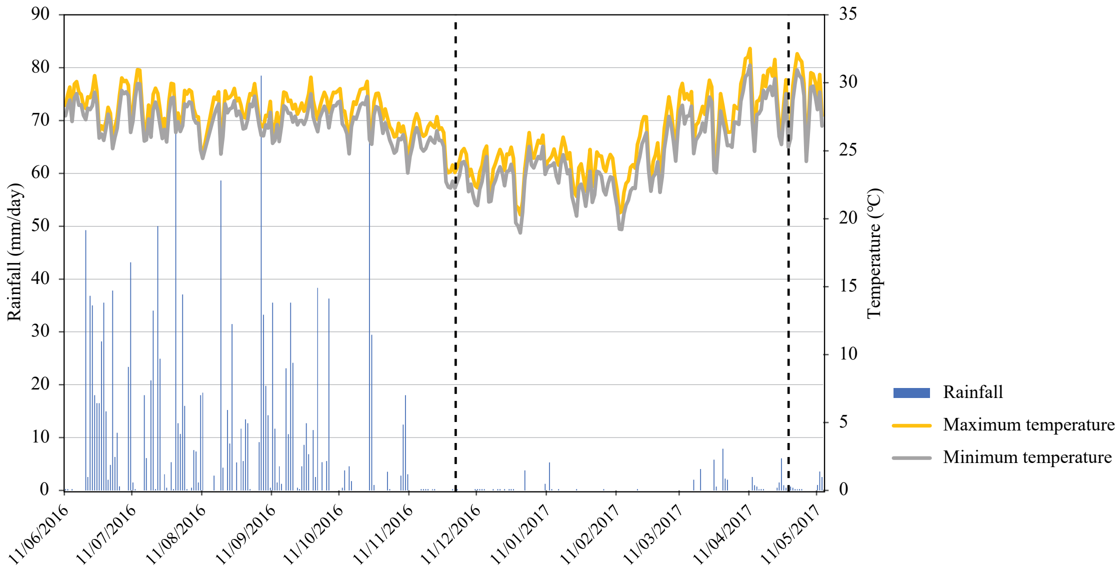
Mobilization of Farmers and GWUG Activities Prior to the Start of Operations

Six farmers were initially interested in participating in the trial, but ultimately, only one of the six actually participated. The reasons provided by the non-participating farmers included the high cost of the water compared to traditional alternatives, lack of labor, and lack of financial capital or access to credit to cover the input costs. The participating farmer had also participated in the first year (i.e., farmer 1) (Figure A6, Appendix 6). Preparation of the irrigation system began with minor repairs being done to ensure the system is ready for the forthcoming irrigation season. This work was carried out by the GWUG with some technical support provided by the field officer. Unlike in the first year, irrigation and maintenance costs were covered in full by the GWUG.

Climate During the 2016-2017 Dry Season

Figure 21 shows the daily rainfall and temperature records for the period from June 2016 to May 2017. Temperatures range, on average, from 20 °C in late January to 33 °C in April, the hottest month of the year. Limited rainfall was recorded over the trial period, with just a few scattered events of less than 10 mm.

FIGURE 21. Meteorological data during the 2016-2017 dry season (average daily value).



Note: The dashed lines indicate the start and end of dry-season cultivation.

Groundwater Level Response and Groundwater Use

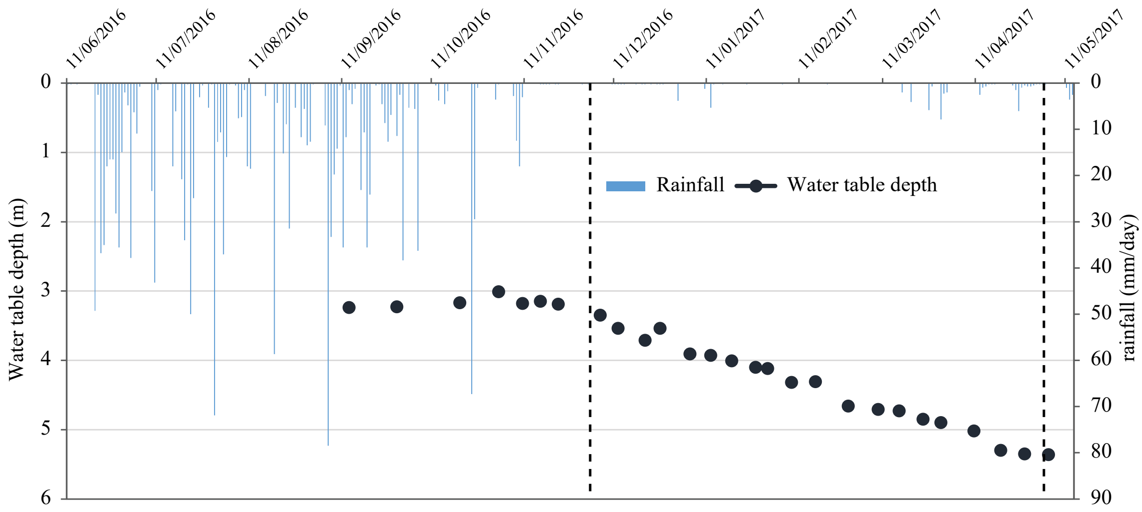
Figure 22 shows the weekly groundwater levels recorded at the observation well situated within the school grounds. These records clearly show that groundwater levels were either stable or rising from September to the beginning of November 2016. Over the course of the dry season, from November onwards, groundwater levels started decreasing until the end of May, when recording of groundwater levels stopped. The maximum change in groundwater levels varied by just over

2 m. There is no evidence of an increase in the rate of decline for the dry-season groundwater recession over the trial period or in the maximum drawdown observed towards the end of the dry season (i.e., 5.4 m in May 2017) compared to that of the previous year (i.e., below 6 m in April 2015 and 2016). Therefore, there is little evidence to suggest that pumping from the irrigation trial has had a negative impact on groundwater levels in the second year of operation.

Cropping Patterns and Agricultural Practices

By late November 2016, following completion of the rice harvest, the participating farmer prepared his fields for dry-season cultivation. The fields were plowed using a two-wheel tractor which was hired for this purpose. Cultivation at the pilot trial commenced on December 4, 2016, and concluded almost 5 months later on April 28, 2017. All agricultural activities were performed by the farmer and his family without hiring additional labor. Field observations indicate no major need for herbicides or pesticides for non-rice crops as weeds were not problematic and insects were not a significant cause of crop damage or losses. For rice cultivation, a Thai-manufactured herbicide containing Haloxyfop-T methyl ester was used to kill weeds. The farmer combined organic (i.e., cow manure and rice-husk biochar) and chemical fertilizers to improve the soil fertility as reported during the first season. Data on the amount of fertilizers applied are not available. The total area cultivated by the participating farmer reached 0.67 ha, or around 10% of the total command area. Crop selection was made individually by farmers with support from Napok Agricultural Research Center and the National Agriculture and Forestry Research Institute.

FIGURE 22. Groundwater level fluctuations and corresponding rainfall patterns between June 2016 and May 2017.

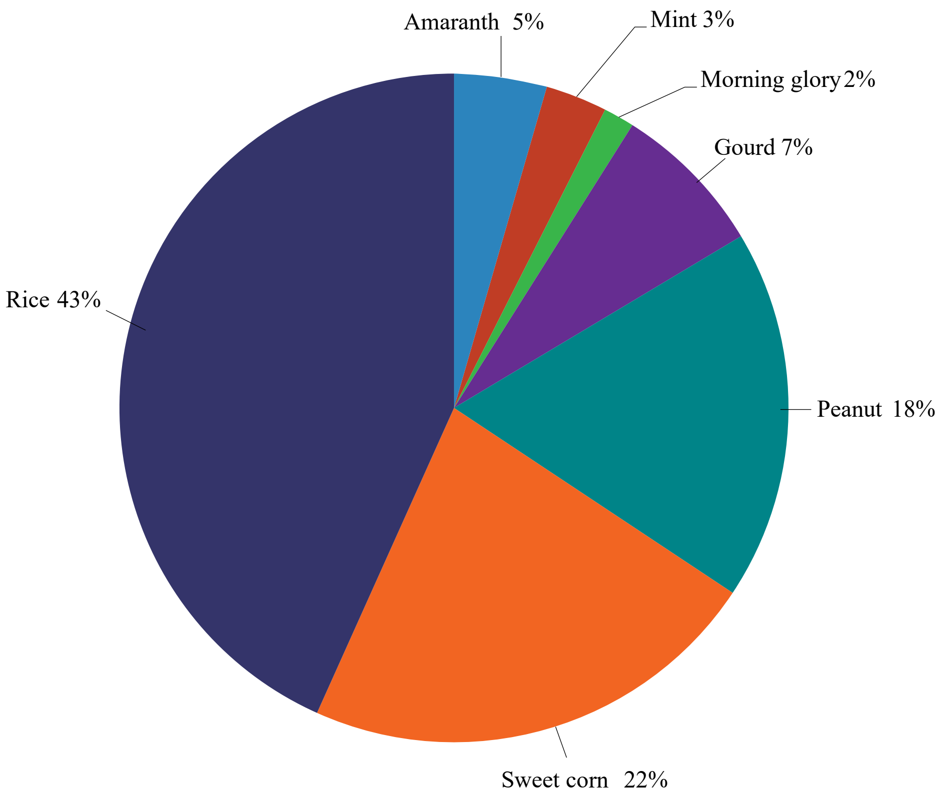


Note: The dashed lines indicate the period of dry-season cultivation.

Cash crops – sweet corn, peanut, and mixed vegetables and herbs – were grown over 57% of the area (Figure 23). The mixed vegetables and herbs included gourd, morning glory and amaranth, among others. Additionally, the participating farmer perceived the system as a means to expand both his home gardening and rice cultivation. Rice covered 43% of the total area. Except for sweet corn and peanut, all seeds were from the farmers' own reserves and all input costs were paid for from their own savings without the need to borrow funds.

Groundwater was the sole source of water for irrigation of all crops except rice. Surface water was initially used to irrigate the paddy field every 3-5 days from the sowing date until the 12th of March, when the surface water supply was exhausted. Thereupon, the farmer used only groundwater to irrigate the paddy field until harvest (i.e., 28th of April). Sprinkler irrigation was used to irrigate all other crops.

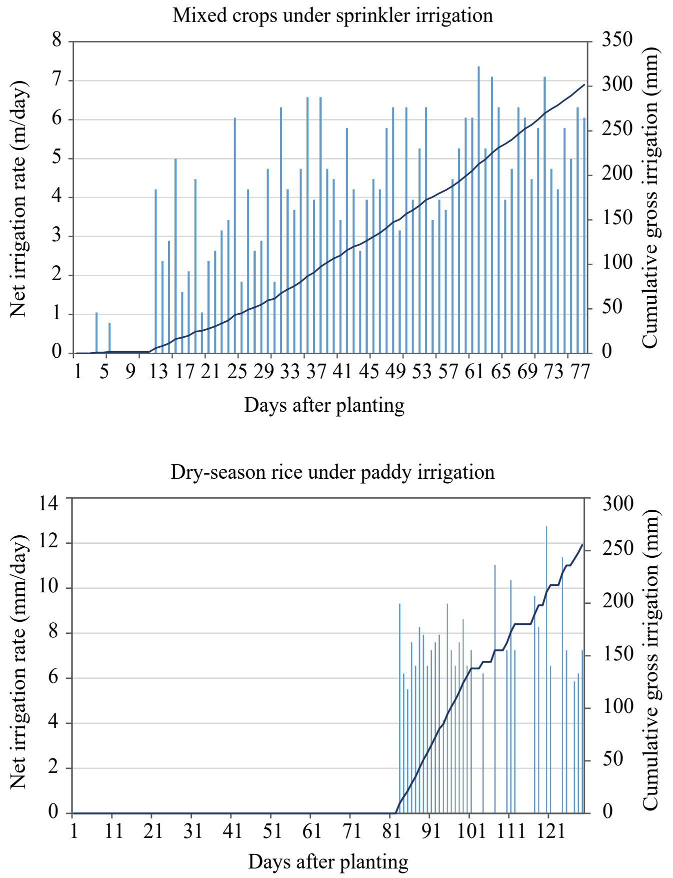
FIGURE 23. Cropping pattern during the 2016-2017 dry season.



Irrigation Timing and Rates

The irrigation timing and net application rate for dry-season rice under paddy irrigation and mixed crop under sprinkler irrigation are shown in Figure 24. The mixed crop category was used, since crop-wise irrigation timing and rate were not available due to the scarcity of data. Field observations revealed that, in the early months of the dry season, demand was lower due to high soil moisture conditions and lower temperatures. When focusing on the irrigation frequencies and rate, dry-season rice was irrigated with groundwater every 2 days out of three at an average rate of 8 mm per application while mixed crops received, on average, 4.4 mm per day.

FIGURE 24. Groundwater irrigation timing and net application rate for each irrigation method.



Note: Crop-wise measurements were not available during the second season.

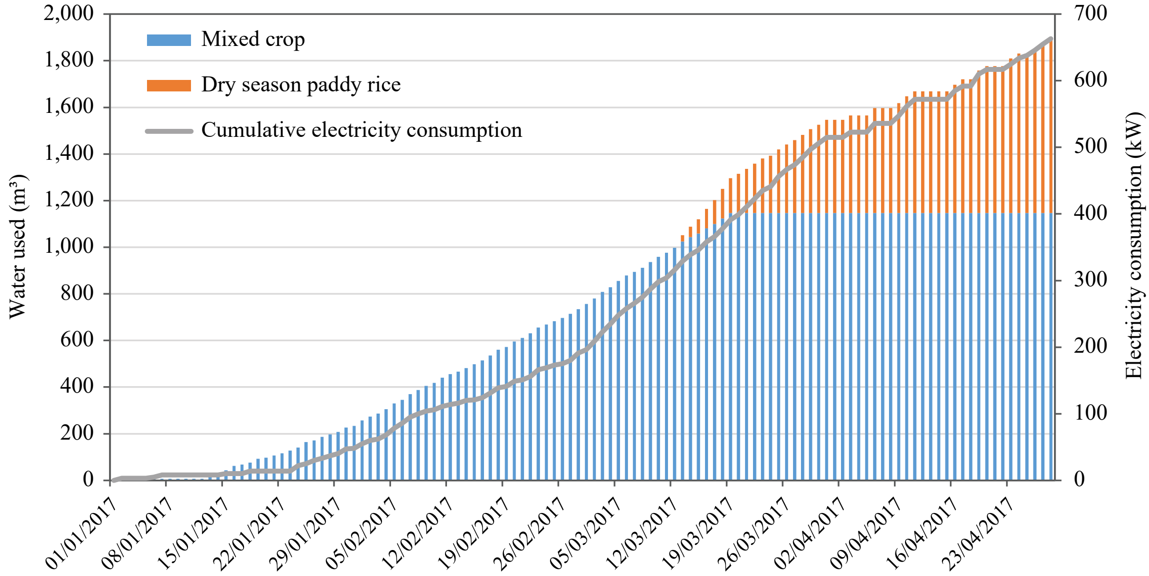
Groundwater Use

Figure 25 shows the groundwater used for rice and non-rice crops over the period of cultivation. The curvilinear trend in cumulative consumption shows that the demand increased along the dry season. Total cumulative groundwater use for non-rice crops over the entire cultivation period was 1,147 m^3 or the equivalent of 302 mm of water. In the case of dry-season rice cultivation, groundwater irrigation begins once surface water supplies had run dry in mid-March. A more uniform trend in cumulative consumption is evident as groundwater use was restricted to just the hottest months. Total cumulative groundwater use was 740 m^3, which equates to 255 mm over the cultivation period. This was lower than non-rice crops, but could be explained by the restricted period of groundwater irrigation. Ultimately, 1,887 m^3 of groundwater was pumped throughout 128 days of cultivation. Sixty-one percent of groundwater was utilized for mixed crops and 39% for paddy.

Irrigation Water Cost

The total electricity consumption over the period shown in Figure 25 was 663 kW with an average usage rate of 5.7 kW/day. Utilization was lower in January and February and higher in March and April reflecting the impact of the irrigation water use. Calculation of the pumping cost was based on the average rate determined in the first year of the trial of USD 0.04/m^3 (LAK 302 LAK/m^3). The farmer was unable to provide copies of the monthly electricity bills issued by EDL. However, he was able to indicate that the bill was in the order of USD 6.1/month (LAK 50,000/month), which is verified by the calculated total pumping cost of USD 24.6 (LAK 200,226).

FIGURE 25. Cumulative water and electricity consumption.



Agricultural Production and Profitability

Crop Yield

Crop yields were generally low, and lower than in the first dry season of operation for the major crops cultivated. Most of the agricultural production was sold at the Ekxang market. A large proportion of the sweet corn was retained and used for animal feeding, as the variety produced by the farmer was not of high quality and could not fetch a sufficient price on the market (Table 11).

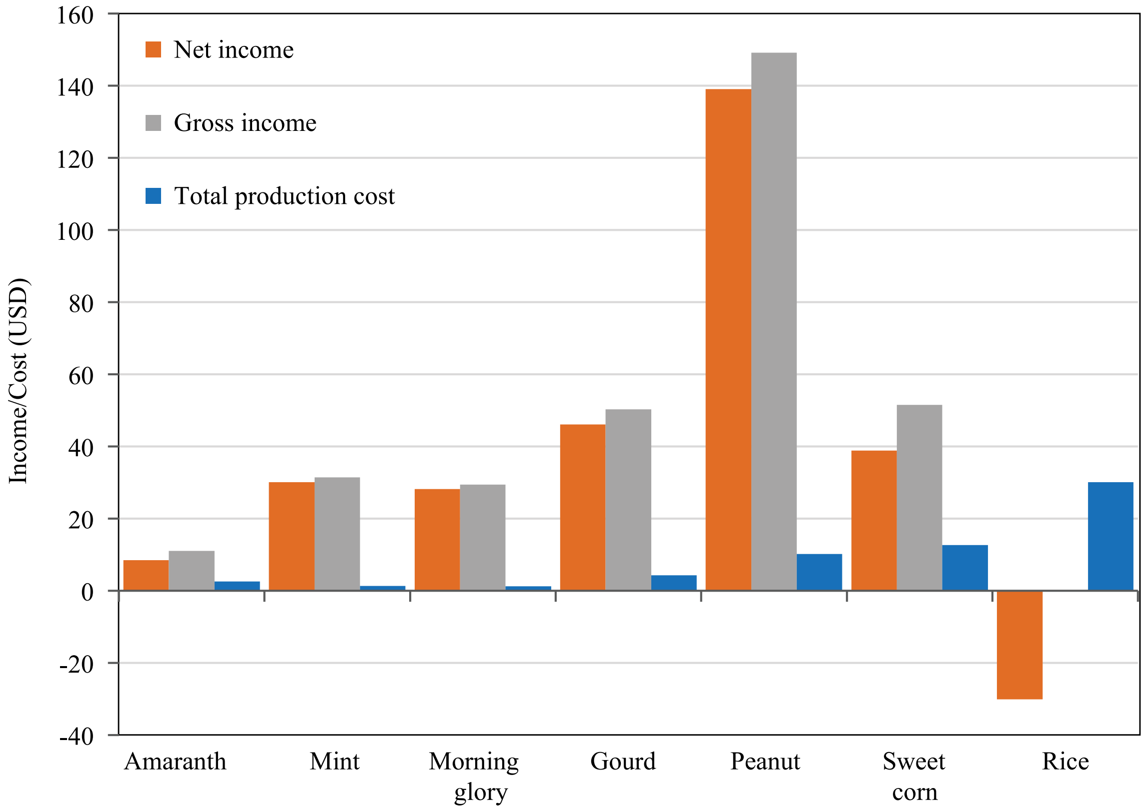
TABLE 11. Overview of crop production.

Crop type		Non-rice crops					
	Rice	Sweet corn	Peanut	Gourd	Amaranth	Morning glory	Mint
Quantity harvested (kg)	113	280	214.7	53.3	30	30	25.6
Quantity retained (kg)	0	112	12	2	0	0	0
Quantity sold (kg)	0	168	202.7	51.3	30	30	25.6
Sale price (USD/kg)	0.31	0.31	0.74	0.98	0.37	0.98	1.23
(LAK/kg)	2,500	2,500	6,000	8,000	3,000	8,000	10,000
Irrigated area (ha)	0.29	0.15	0.12	0.05	0.03	0.02	0.01
Crop yield (t/ha)	0.4	1.9	1.8	1.1	1.0	1.5	2.6

Profitability

Net incomes were highest for peanut, followed by gourd, sweet corn, mint, morning glory, amaranth and rice (Figure 26). The total gross and net incomes of the farmer were USD 320 (LAK 2.63 million) and USD 259 (LAK 2.12 million), respectively. Despite being less, the USD 259 (LAK 2.12 million) in income received over the dry season is significant compared to the net income of USD 588.9 (LAK 4.8 million) the farmer gained from wet-season production of glutinous rice cultivated over the same area (data not shown). Total net income on a per hectare basis reached USD 389/ha (LAK 3.2 million/ha) and input costs accounted for USD 62 or LAK 0.5 million or USD 93/ha (LAK 700,000/ha). In proportional terms, the costs of inputs relative to the gross income was highest for sweet corn due to the low sale price and the relatively high water requirement. Mint and morning glory (both 4%) were the lowest. It is important to mention that rice was cultivated for household consumption and not as a way of gaining income.

FIGURE 26. Total production cost incurred, and gross and net incomes received by the farmer on a crop-wise basis.



DISCUSSION

Through the process of establishing and evaluating the pilot trial in Ekxang village, which involved regular interaction of the project team with the farmers and other stakeholders, a set of key topics of interest have emerged that help shed light on the functioning, performance and sustainability of the trial at the farm and system levels. The insights on these topics come not only from this study, but also from parallel studies that have more rigorously evaluated farmer perceptions of groundwater use throughout Ekxang village (Suhardiman et al. 2016, Forthcoming). Each topic is discussed below. The main lessons learned for community-managed groundwater irrigation in Laos are also discussed.

GWUG Functioning

Despite the limited size of the GWUG and the duration of the trial, the GWUG has shown positive signs of progress. Farmers were fully involved in operating the system and in recording their own water use. Communication with the project team was also always fruitful in revealing general day-to-day and bigger issues. The GWUG reported a few maintenance issues to the project team and fixed problems with the irrigation system when the work was within their capabilities; a good indicator that the irrigation system was being valued. Participating farmers generally provided positive feedback to other villagers.

Over both years of the trial, the head and deputies of the GWUG did not cultivate crops at the pilot trial site. Hence, interactions with the members were limited. It is also noteworthy to add that, as the project subsidized the pumping costs and many of the maintenance expenses in the first year, the mandates of the GWUG were limited to an advisory role. Moreover, considering the small size of the GWUG in both years, their management role was limited. Strengthened cohesion of the GWUG would be likely if at least one of the members was either the head or a deputy of the GWUG.

Two of the elected leaders also have other administrative responsibilities in the village as the head and accountant of the Agricultural Production Group. Their skills, which are relevant to the functioning of the GWUG, could be seen as a broader asset. Village leaders are also more likely to have connections with higher-level institutions such as DAFO or PAFO, which could provide long-term technical support. Besides this, DAFO and PAFO officials are responsible for providing guidance and support to the GWUG regarding their functioning, agricultural planning and practices. However, their lack of resources, expertise and technical guidance might have limited the expansion and autonomy of the GWUG.

A practical example of the farmers' capacity and initiative to organize themselves effectively emerged following the third year of operation. The GWUG mobilized financial resources through the Agricultural Production Group to purchase a dedicated water pump for the nadon site, in order to allow farmers to arrive with their two-wheel tractors and pump water on a rotational basis. This information was shared with the project team during the most recent site visit (i.e., March 20, 2018).

Farmers' Perceptions and Adoption Trends

Farmers' sense of ownership of an irrigation system is dependent on the perceived level of risk involved and the capacity to see tangible benefits emerge. This is a key indicator of project adoption and sustainability (Ricks 2015). Caution by the farmers towards adoption of new water-saving technologies is likely due to their lack of experience in the use of pipe distribution systems, water-saving equipment and higher performing pumps. Operating and maintaining such technologies certainly require training, experience and links to suppliers of equipment, which was quite challenging for farmers that were used to their accustomed norms.

From the perspective of farmers in Ekxang village, the value of the system is determined by water delivery capacity and reliability, operating costs and profitability of crop production. At first, farmers expressed some skepticism about the capacity and reliability of the irrigation system. Engagement in the pilot trial was at that stage perceived as being risky. The costs incurred by farmers in dry-season cultivation was of high importance, and there was no guarantee that the system would supply enough water to cultivate crops and that it would be profitable. The long duration of the planning and establishment phase of the trial also contributed to a sense of caution among farmers. They needed to test the system first without the risk of financial losses in case of failure. The project team agreed to subsidize the pumping and maintenance costs in the first year as an incentive for farmers to engage in the trial. Hence, the farmers only had to pay for the variable costs related to crop production. By the end of the first year, farmers' views had generally become more positive. Most importantly in this respect, the supply of water was demonstrated to be available throughout the dry season. By perceiving the irrigation system's potential in terms of its profitability, the findings from the first year suggested that farmers had progressively developed some sense of ownership and started to undertake maintenance tasks independently. However, results from the second year of operation when subsidies had been lifted, although somewhat surprising, showed clearly that adoption of the irrigation system by the local communities was still far from ideal. As one of the key findings of this study, further examination is given in the sections below. In the third year, two farmers participated, without any form of engagement from the project team, and the irrigated area was increased marginally from 0.67 ha to around 1 ha.

Water Management

The irrigation practices applied by the participating farmers were far from optimal in terms of crop selection and rates of water application. This was despite the training and advice provided by the project team on such matters, and in part due to the subsidy on the pumping costs provided in the first year. Over both years of dry-season rice cultivation, the irrigation system was unable to meet the high water demand and deliver sufficient water when the source switched from canal water to groundwater. Despite the strong historical and cultural pull towards rice cultivation in the region (Schiller et al. 2006), it is clearly an inappropriate dry-season crop at this site. This is gradually being realized by farmers and, according to the most recent interview with the village head, the system was utilized only for non-rice crops in the third year. Farmers who used water-saving irrigation technologies (drip and sprinkler) in the first year overused water due to a lack of prior experience and the subsidized water. Water applied to the field could have been reduced by 50 to 60% in some cases, which would have reduced the cost of pumping. Even in the second year using sprinkler irrigation without the subsidy, water use could have still reduced pumping by approximately 40 to 50%. Use of furrow irrigation in the first year relied on a typically high amount of water to reach the crop. Considering that villagers traditionally use this irrigation method, the results were not surprising. This highlights that farmers would require more support on crop water needs, irrigation rotation and water delivery system, which would likely expand utilization of the irrigation system.

Agricultural Practices

Monitoring of farmer practices suggested that the fertilizer applied and pest and weed management were insufficient to bridge yield gaps. Farmers combined the use of organic and chemical fertilizers to improve soil fertility and water-holding capacity. However, considering the low yields obtained for watermelon and sweet corn in the first year of operation and the very low yields obtained for most crops in the second year, further investments in fertilizer or weed management would result in higher crop yields and greater farmer benefits (Linquist et al. 2007). An in-depth fertilizer assessment would allow farmers more precision in fertilizer application. In addition, the implementation of Integrated Pest Management techniques is advisable rather than systematic application of ‘broad-spectrum’ insecticides as was observed. Real pest threats and issues related to the frequent use of pesticides must be clearly assessed and taken into consideration by farmers. Such assessments require the involvement of agricultural support agencies such as DAFO and PAFO and other local extension services (e.g., Phone Soung Agriculture Development Center). These types of assessments should not necessarily be limited to GWUG members, but could also be done at the village level.

It is worth further highlighting the importance of rice cultivation for local farmers. Despite the irrigation system being inadequate to provide water for dry-season rice production, farmers still do so. This is, in part, motivated by the lower labor requirement overall, giving what was believed to be an attractive economic return on their labor. To reduce the high labor required for transplanting, farmers choose direct seeding of rice, which in turn induced serious weed problems. The need to cultivate dry-season rice is also dependent on the wet-season rice yield as the farmers’ seek to be self-sufficient in rice.

Although both PAFO and DAFO representatives were routinely invited to participate and contribute in all phases of the project, their involvement was limited due to competing commitments elsewhere. Their support could be useful to the GWUG and they could provide technical assistance on good agricultural management practices related to water-use efficiency and market-oriented cropping choices. Overall, external support from local institutions are often well received by farmers, since these institutions have a solid understanding of the local context and provide relevant advice on improved practices. For example, the guidance of Dr. Phetmanyseng Xangsayasane (Napok Agricultural Research Center) during the second year in growing peanuts was considered of great value, as farmers had no previous experience with this particular crop.

Financial Aspects

In both dry seasons, the Ekxang groundwater irrigation system has shown its potential to generate profits for the farmers involved. Thus, the costs incurred by dry-season cultivation do not seem to be a sufficient argument for the limitations in farmer interest observed. However, with the relatively higher cost to abstract groundwater compared with other irrigation alternatives (i.e., unlined dug wells and surface irrigation canals), comes greater need to ensure market-oriented crop selection, taking account of market price volatility. The financial viability indicators presented earlier showed that, by enhancing the agricultural practices and water management, and with a wider involvement of farmers, this type of irrigation system would certainly be financially viable.

Household Labor and Competition with Alternative Livelihood Strategies

Lack of labor is considered one of the main constraints to agricultural development in Laos (Vote et al. 2015). As an important determinant of the livelihood strategies employed by farming households, household labor was identified as a major factor determining farmers’ engagement in utilizing groundwater for agriculture in the village (Suhardiman et al. 2016). While farming households with sufficient family labor have an interest in expanding their farming activities through cash crop production, households with labor shortages (i.e., 60% of the surveyed households in Ekxang village) tended to engage in other on- or off-farm activities (Suhardiman et al. Forthcoming). The hiring of extra labor, where deemed necessary, adds significantly to input costs and thereby affects profitability (Suhardiman et al. Forthcoming). In particular, small households with limited financial capital could not afford to hire extra labor and were thus unable to participate in the irrigation trial.

Farmers involved in the trial had at least three people available within the household to work in the field. Nonetheless, during the first year, farmers 1 and 2 had, and could afford, to hire additional labor for specific tasks. Growing dry-season rice was seen as a way of overcoming labor shortages incurred by cash crop cultivation.

Some farmers of the village have other well-established livelihood options such as running small businesses or working as manual laborers (e.g., in construction). These activities can generate attractive incomes and may overlap with dry-season cultivation. Opportunities for off-farm employment are also quite common in villages, such as Ekxang, which are within close proximity to the larger towns and cities, and which could cause temporary or permanent migration of household members (Suhardiman et al. 2016). As per the study conducted by Manivong et al. (2014) on Champasak Province in southern Laos, it is most likely that the youth of working age (i.e., unmarried sons and daughters) are encouraged towards activities outside of the agriculture sector, thereby creating a labor vacuum within the village, which in turn increases the labor cost and constrains agricultural development.

Land Rights and Social Equity

All farmers involved in the pilot trial own the fields they cultivate. Land tenure rights over the irrigation command area does not seem, in theory, to be a factor that prevents farmers from renting land. At the same time, only landowners were engaged in the GWUG. Before the trial commenced, landowners gave verbal agreement to village authorities to grant command area land over the dry season to farmers who were willing to cultivate crops on their land. Scope for the poorer farmers to rent land seems to have limited potential in the village given that only 3% of households are landless and 6% do not own paddy land (Suhardiman et al. 2016). Still, it is perhaps surprising that a greater number of poor farmers, with fewer livelihood options, did not show more interest toward the irrigation system. One reason could be that the cost incurred for cash crop cultivation and the “capital investment” it required over few months were already too high for the poorest households. Therefore, their involvement would require greater support to overcome constraints such as labor shortfall or lack of investment capital for inputs. Those seeking to rent land could also perhaps be disempowered by an undue sense of indebtedness to farmers that own land, due to the possibility of not being able to easily repay the rent. Often these types of concerns are internalized and, therefore, not directly articulated (Gebert 2010). The poor within a community commonly face difficulties in fully integrating in village institutions, as their lack of power and influence leaves them easily excluded from planning and decision-making processes.

External Technical Support

An extended engagement process between the village community and the project team was needed to create the necessary capacity within the GWUG. The existing constraints discussed earlier indicate that GWUG members require ongoing technical support in relation to crop selection, agricultural practices and water management in order to operate and manage the irrigation system effectively. The GWUG would benefit greatly from enhanced support from higher-level institutions.

Lessons Emerging from Site Selection

The selection of Ekxang village in Phonhong District as the study site was made by the project team on the basis of the hydrogeological characteristics of the area, perceptions on the need for dry-season irrigation and level of community interest. The convenience of site access due to the proximity to Vientiane Capital was another important factor. This district was generally considered to have good groundwater resource potential, agricultural soils and market access. Low rates of poverty in the district, 9.9% compared with 24.8% nationally (Coulombe et al. 2016), suggest a rural community generally wealthier than average.

The need for dry-season irrigation and adequate and reliable groundwater availability are clearly essential prerequisites. Assessment of farmers' irrigation needs is a relatively straightforward matter (Field et al. 1996), whereas sound hydrogeological assessments are severely hampered by the lack of data throughout Laos (Viossanges et al. 2018). Equally important is a sound, upfront understanding of the rural socio-demographics (e.g., household labor availability, household assets, farm size, crops grown, land tenure arrangements) and livelihood strategies (e.g., other on- and off-farm activities, migration). All these factors help to better establish the agro-socioeconomic context. This is not that straightforward to achieve as it requires multi-disciplinary efforts and coordination. It is likely that the focus group discussions conducted in Ekxang during the site selection process did not allow the project team to fully grasp that farmers had access to other livelihood options that outcompete further agricultural development in the village. Similarly, labor shortage was not highlighted upfront as an important constraint. These factors could be the major causes for the low level of adoption of the irrigation system in the village.

CONCLUSIONS

The first community-managed groundwater irrigation system in Lao PDR has been established at Ekxang village and is fully operational. The GWUG has been formalized and is under the jurisdiction of the respective provincial and district agriculture and forestry offices (i.e., PAFO, Vientiane, and DAFO, Phonhong). Despite the small size of the GWUG and the challenges faced during the 2 years of this trial, the diversity of crops cultivated and agricultural practices employed by the participating farmers have delivered valuable results. Analysis of the data collected on agronomic and financial performance as well as functioning of the GWUG allowed the project team to identify many lessons for successful operation and sound evaluation of the trial. Cash crops and small vegetable cultivation – which the system was designed for – generated profits to farmers, whereas paddy rice cultivation was not profitable due to the high irrigation water requirement.

Over the first year of operation, farmers progressively developed a sense of ownership over the irrigation system and were able to observe the practical benefits to be gained from participating in the system. While this could have been the stepping-stone for wider adoption, expansion of the GWUG did not occur during the second year (although it did pick up slightly in the third year after the study had concluded). The abrupt withdrawal of project subsidies after the first year was one of the determining factors for limited adoption over the short term. Other, perennial, determining factors likely included farmers' engagement in alternative livelihood options, and lack of household labor and external technical support. Our results highlight that a detailed upfront understanding of farmers' needs, traditional value systems and practices linked to cultivation and food security, existing livelihood options and socioeconomic status are as important as understanding the groundwater resource capacity and irrigation demand, in order to maximize adoption and promote sustainable operation of the irrigation system. Therefore, a more rigorous multi-disciplinary approach is strongly recommended for similar initiatives in the future. Successful implementation of community-managed groundwater irrigation relies on an adequate level of farmer understanding and motivation, which drives participation, organization and hence overall system functioning and sustainability. These lessons also make clear the valuable lesson that an over-reliance on technical considerations may not guarantee farmer adoption, given the importance of other, non-technical factors at play in any given agrarian context.

The development potential of groundwater for irrigation in Lao PDR is high. The way forward for farmers to make best use of the available groundwater resources, where there is a clearly defined need, depends upon gaining a better understanding of the hydrogeological systems at the local level, defining more precisely the scope for groundwater irrigation development, empowering farmers through knowledge and technical support, and accounting for the local culture and other contextual factors. These prerequisites would provide wider opportunities for agricultural groundwater development in Lao PDR.

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APPENDICES

Appendix 1. Characteristics of Farming Activities of Ekxang Village and Socioeconomic Profile of GWUG Members.

TABLE A1.1. Characteristics of the farming households (HH) in Ekxang village.

Household activities	Proportion (HH/total HH)	Percentage
Paddy cultivation	72/80	90%
- for home consumption	*67/80*	*84%*
Fruit and vegetable cultivation	58/80	73%
- for home consumption	*38/80*	*48%*
Household irrigation characteristics		
Size of Irrigated area more than 0.32 ha (2 *rai*)	10/72	14%
Type of well		
- Private lined concrete well, "ring well"	*77/80*	*97%*
- Private unlined dug well	*40/80*	*50%*
- Borehole well	*0/80*	*0%*
Agricultural losses due to water shortage in the last 5 years	43/80	54%

Source: IWMI survey of 80 out of 236 randomly selected households in Ekxang village in 2014 (n=80) and in 2016 (n=72).
Note: 8 of the 80 households surveyed in 2014 could not be reached in 2016 for various reasons.

TABLE A1.2. Socioeconomic profile of GWUG members in year 1 and average value for the village.

	Farmer 1	Farmer 2	Farmer 3	Farmer 4	Ekxang village (n=72)
Sex of household head	Male	Male	Male	Male	81% male
Age of household head	44	58	41	55	55
Size of household	8	5	3	4	4.8
Household labor	3	4	3	3	
Level of education of household head	Primary school	Primary school	-	Primary school	Secondary school
Area of irrigated land (owned)	0.06	0.04	0.96 (rented)	0.96	0.12
Area of paddy land (owned)	0.8	1.0	1.92 (rented)	1.5	1.08
Number of cattle (owned)	5	0	0	4	9
Agricultural machinery	-	Two-wheel tractor	Two-wheel tractor	Two-wheel tractor	64% own a two-wheel tractor
Vehicle (car)	-	-	-	-	28% own a car

Source: IWMI survey of 72 out of 236 randomly selected households in Ekxang village in 2016.

Appendix 2. Calculation of Irrigation Water Costs.

TABLE A2. Calculation model of the electricity bill - details of the electricity bill for the month of April 2016.

Electricity consumption (kW)	Electricity range (kW)	Electricity price (USD)	Electricity fee (USD)
25	0-25	0.04	1.07
125	26-150	0.05	6.35
1,480	151+	0.12	181.41
Variable cost (excluding tax)			188.83
Fixed cost (excluding tax)			0.64
Total (excluding tax)			189.47
Tax: 10% of the fixed and variable costs			18.95
Total (including tax)			**208.42**

FIGURE A2.1. Evolution of electricity costs in relation to electricity consumption.

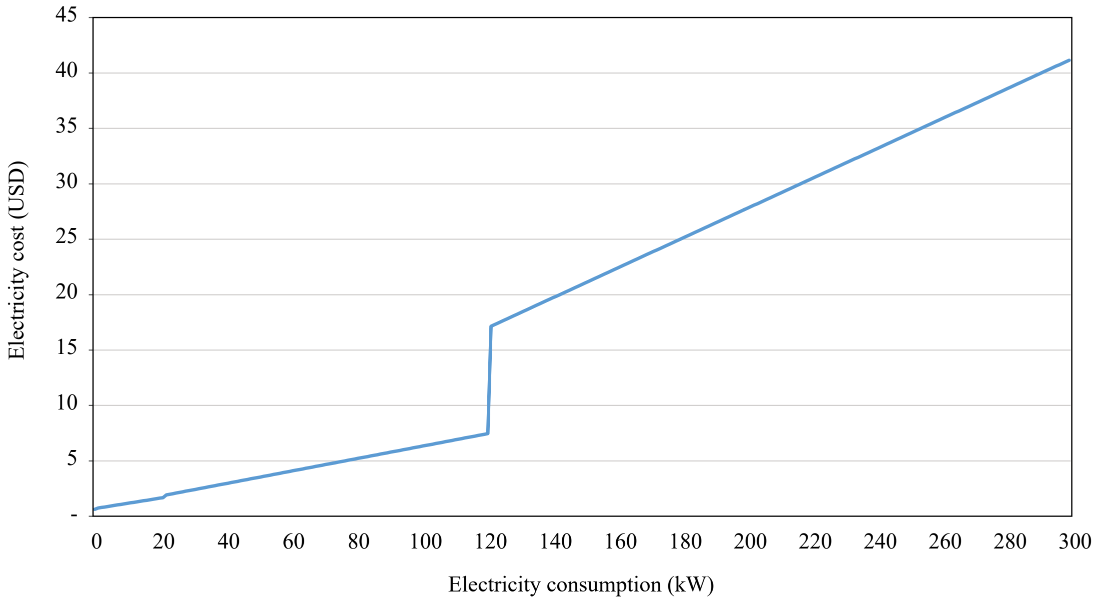
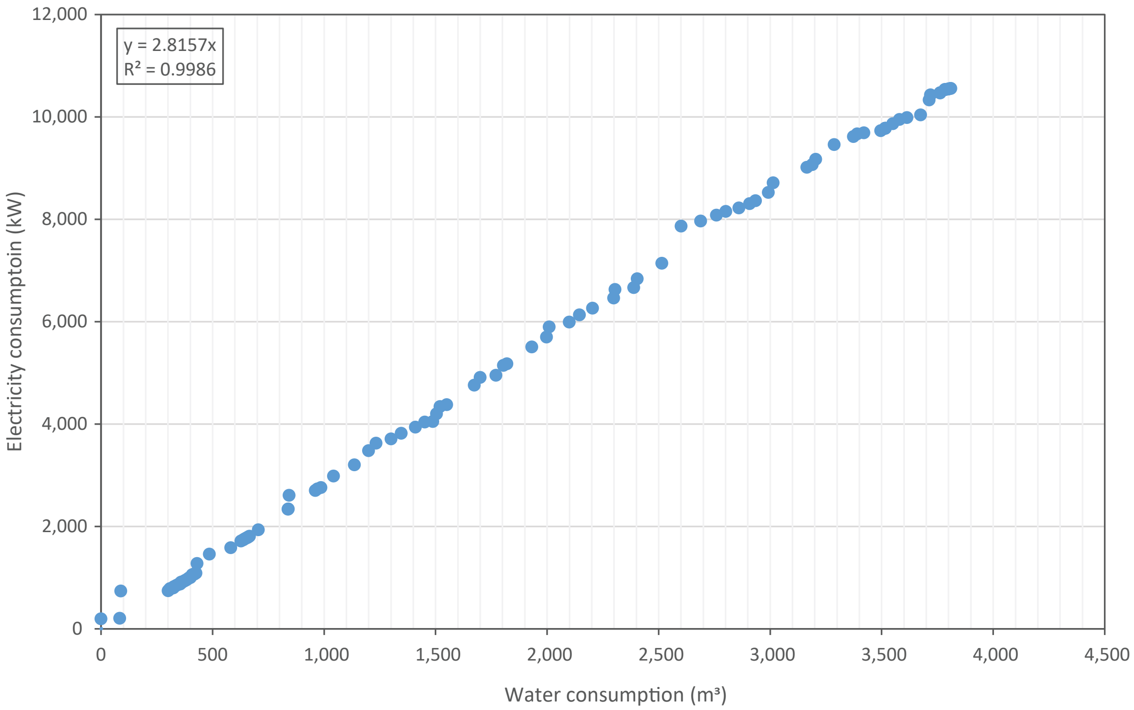


FIGURE A2.2. Energy consumed due to groundwater pumping.



Appendix 3. Inputs Used and Outputs Produced by the CROPWAT Model.

TABLE A3.1. List of inputs required and outputs produced by the CROPWAT model.

Data	Input	Source of input	Output
Climatic	Minimum and maximum temperature (daily means) Relative humidity Sunshine duration Wind speed Rainfall (daily)	Weather station CLIMWAT 2.0 database (Smith 1993)	Reference evapotranspiration (ETo) (Penman-Monteith formula)
Crop	Crop coefficient (Kc) Crop description Maximum rooting depth Percentage of area covered by plant	Doorenbos et al. 1979 Allen et al. 1998 Farmer interviews Field investigations	Actual crop evapotranspiration (ETc) Crop water requirement Irrigation water requirement (IR)
Soil	Initial soil moisture conditions Available soil moisture	CROPWAT database Soil sampling	Soil moisture depletion
Irrigation	Irrigation schedule (timing and rate)	GWUG records	Estimated yield reduction due to water stress Irrigation efficiency

TABLE A3.2. Soil characteristics used in the CROPWAT model.

Soil name: Black Clay Soil		
General soil data	Value	Units
Total available soil moisture (FC - WP = TAW)	150	mm/meters
Maximum rainfall infiltration rate	25	mm/day
Maximum rooting depth	20	centimeters
Initial soil moisture depletion (as % of TAW)	20	%
Initial available soil moisture	120	mm/meters
Drainable porosity (SAT - FC)	40	%
Critical depletion for puddle cracking	0.6	mm/day
Water availability at planting	80	% TAW
Maximum water depth	30	mm

Source: Allen et al. 1998.
Notes: FC - Field capacity, WP - Wilting point, SAT - Soil moisture at saturation, TAW - Total available water (TAW = SAT - WP).

Appendix 4. Farmers' Cropping Strategies and Sowing Density in Year 1 of the Trial.

FIGURE A4. Farmers' cropping strategies (ha).

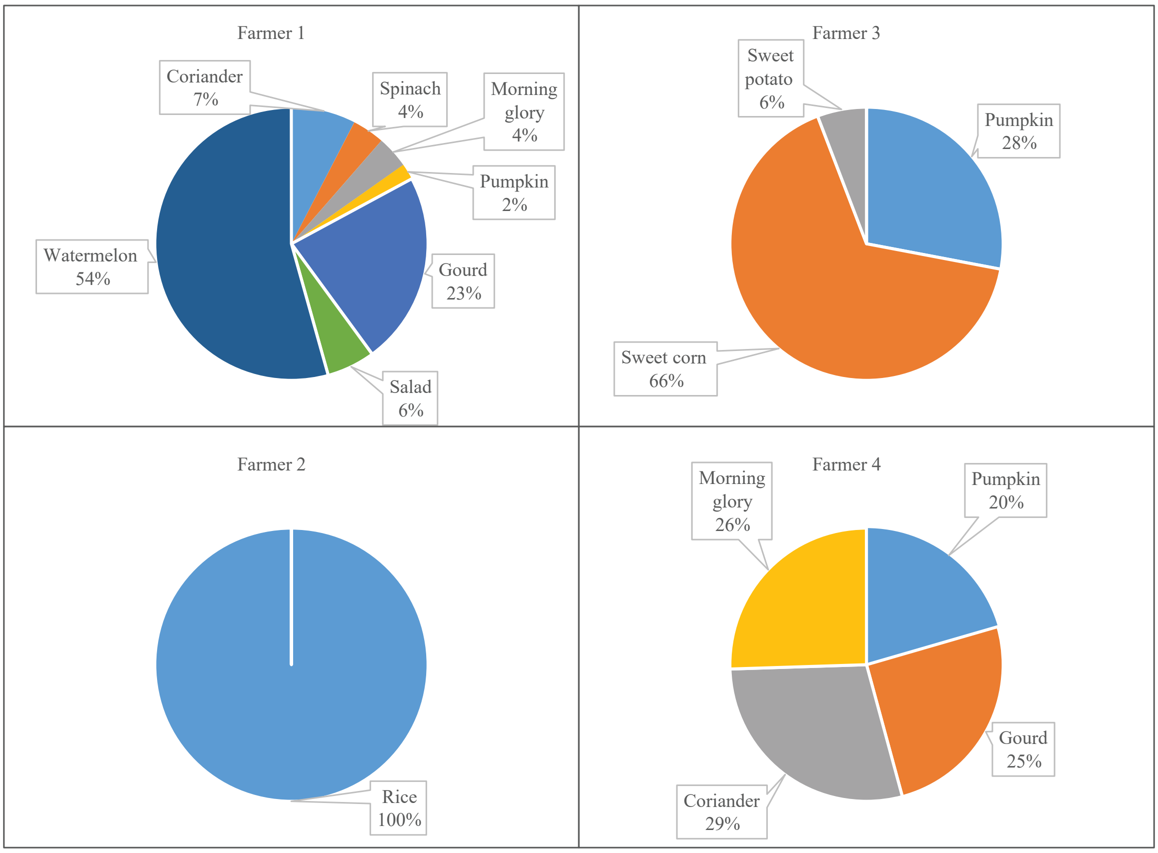


TABLE A4. Sowing density per crop type.

Crop type	Sowing density (plants/m²)
Sweet potato	13.7
Morning glory	113
Snake gourd	2
Coriander	62
Salad	36
Watermelon	2
Sweet corn (monocrop)	5
Sweet corn (mixed intercrop)	1
Pumpkin	1

Source: Authors' survey.

Appendix 5. Crop Yield, Production, Sale Price and Farmers' Income in Year 1.

TABLE A5.1. Crop yield (t/ha).

	Farmer 1	Farmer 2	Farmer 3	Farmer 4	Vientiane Plain[1]
Coriander	5.11			0.06	-
Gourd	9.52			0.27	5.89
Morning glory	7.64			0.22	9.71
Pumpkin	5.71		2.10	0.14	5.89
Rice (dry season)		0.74			4.75
Salad	9.52				9.71
Spinach	9.29				9.71
Sweet corn			0.89		10.42
Sweet potato			3.85		12.01
Watermelon	5.00				14.41

[1] *Source:* Lao Census of Agriculture. 2014. Agricultural Statistics Yearbook. Agricultural Census Office, Department of Planning, Ministry of Agriculture and Forestry. Data: Average yield in Vientiane Province for the period 2012-2014.

TABLE A5.2. Crop production (kg) and sale price (USD/kg).

	Farmer 1		Farmer 2		Farmer 3		Farmer 4	
	kg	USD/kg	kg	USD/kg	kg	USD/kg	kg	USD/kg
Coriander	143	0.74					3	1.23
Gourd	800	0.61					12	0.51
Morning glory	107	0.92					10	0.37
Pumpkin	40	0.55			121	0.55	5	0.55
Rice			559	0.31				
Salad	200	0.33						
Spinach	130	0.31						
Sweet corn					121	0.61		
Sweet potato					46	1.18		
Watermelon[1]	1,000	0.23						

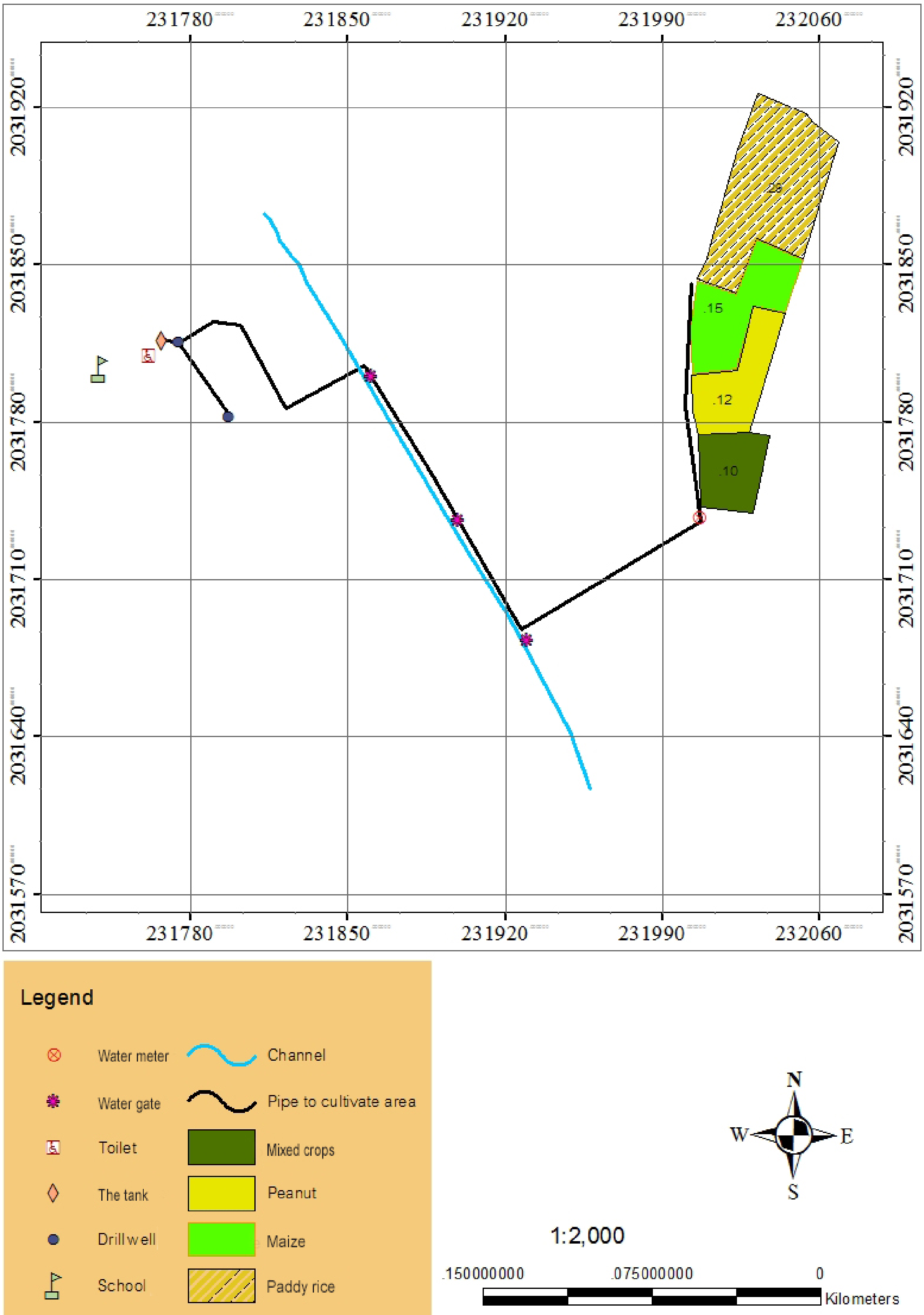
Note: [1] Number of fruits and not per kilogram.

TABLE A5.3. Gross income (USD).

	Farmer 1	Farmer 2	Farmer 3	Farmer 4
Coriander	103.1			3.7
Gourd	490.8			6.1
Morning glory	87.4			3.7
Pumpkin	22.1		66.8	2.8
Rice		171.8		
Salad	66.3			
Spinach	39.9			
Sweet corn			74.2	
Sweet potato			53.9	
Watermelon	233.1			
Total	**1,042.7**	**171.8**	**194.9**	**16.3**

Appendix 6. Map of the Study Site in Year 2 of the Pilot Trial.

FIGURE A6. Map of the study site showing the crop types and areas cultivated in 2016/2017.



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