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TECHNICAL REPORT

Importance of basic cultivation techniques to increase irrigated rice yields in Tanzania

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Abstract The productivity of irrigated rice is low in Tanzania. We hypothesized that this is caused by the absence of a packaged application of basic cultivation techniques. A baseline survey of 31 rice irrigation schemes across the country revealed that a large proportion of fields were cultivated without a technical package. Thus, a package was introduced to each of the 31 schemes through a farmer-to-farmer (FTF) extension approach. First, selected key farmers (KFs) were trained with the basic cultivation techniques at agricultural training institutes. Second, the KFs transferred their knowledge to intermediate farmers (IFs) by working together at a demo-field established in each scheme. Third, the KFs and IFs exhibited the rice performance to other farmers (OFs). The paddy yield across the 31 schemes greatly increased from the pre-training level of 2.4 t ha^{-1} to 3.6 t ha^{-1}after the FTF extension. However, the farmer interviews in the four selected schemes suggested that the technical package was not adopted by all farmers owing to the time-consuming nature of the FTF extension. It was inferred from our study that the low productivity of irrigated rice is caused by the absence of basic cultivation techniques in Tanzania. However, the post-training yield remained relatively low compared with high-yields (4.3–8.4 t ha^{-1}) recorded in cultivar selection trials and high-performing schemes in the county. This "yield gap" could be partly ascribed to the insufficient technical diffusion and the technique-dependent adoption among OFs.

Keywords Basic cultivation technique · Farmer-to-farmer extension · Irrigated rice · Tanzania · Technology dissemination

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Introduction

Tanzania has a relatively long history of rice (*Oryza sativa* L.) cultivation under irrigation. A limited number of records show that rice was grown under irrigated conditions in the Kilombero Valley, Morogoro (Kato 2007), and Usangu basin, Mbeya (Kadigi et al. 2004) as early as the beginning of the nineteenth century. In 1948, the colonial government introduced a 1000-ha modern irrigation system at Kilangani, Morogoro (Therkildsen 2011). Rice consumption increased from the 1960s (USDA 2015) due to a shift in consumer preference from the traditional staples (maize, tubers, etc.) to rice among the urban population. After the 1967 Arusha Declaration (policy on socialism and self-reliance), financial support for state-owned rice irrigation schemes was received from major donor countries, including China and North Korea (Therkildsen 2011). Moreover, trade liberalization in 1986 attracted many private traders to the rice market (Kato 2007), and the profitability of the rice trade encouraged many farmers to develop small-scale irrigation (Meertens et al. 1999; Kadigi et al. 2004). As a means of poverty reduction and food security, the government has made substantial efforts in rehabilitating existing irrigation facilities and constructing new irrigation schemes (MoWI (Ministry of Water and Irrigation) 2009). Presently, there are 624 rice irrigation schemes of approximately 110,000 ha across the country. If irrigation schemes that grow rice sequentially with other crops are also included, the number increases to 1253 irrigation schemes of approximately 240,000 ha.

The productivity of irrigated rice is very low at the farmer level in Tanzania. In cultivar selection trials from 1987 to 1992, Kanyeka et al. (2004) reported that improved (TXD85 and TXD88) and local (Supa) cultivars of irrigated rice produced 4.7–8.1 and 4.5–5.9 t ha^{-1}, respectively. Ikegami (1995) reported that the Lower Moshi Irrigation Scheme (LMIS, 1100 ha) constructed in 1987 under the financial cooperation between Tanzania and Japan recorded a paddy yield of 4.6–8.4 t ha^{-1} from 1987 to 1991. In 2014, LMIS produced the high yield of 6.6 t ha^{-1}, according to data from the scheme management office (personal communication). In contrast, the Tanzanian Rice Development Strategy estimated the national average yield of irrigated rice at 2.1 t ha^{-1} (MAFC 2009). Nakano and Kajisa (2013, 2014) reported an irrigated rice yield of 3.8, 3.5 and 4.6 t ha^{-1} in Morogoro, Mbeya and Shinyanga, respectively, based on an extensive survey in 2009. Lankford (2004) estimated an irrigated rice yield in the Usangu basin of 2.5 t ha^{-1} by reviewing several development project documents from the late 1980s to the early 1990s. Mwaseba et al. (2007) observed an irrigated rice yield of 1.1–2.1 t ha^{-1} in Kyela and Kilombero from 2001 to 2003. These reports suggest that the productivity of irrigated rice in the fields of farmers is much lower than that recorded in the cultivar selection trials and LMIS, although the underlying reason is still unclear. Moreover, since no yield gap analysis has been conducted, the potential yield of rice in the country is still unknown (Saito et al. 2013).

Yoshida (1981) analyzed cultivation techniques of high-yielding farmers in Japan, and he suggested that the high productivity of irrigated rice could be achieved through the packaged application of cultivation techniques rather than the introduction of single advanced technology. Mwaseba et al. (2007) observed that improved cultivars had higher yields when grown with basic cultivation techniques than being grown without them in Kilombero. Nakano and Kajisa (2013, 2014) also observed that improved cultivars performed efficiently when combined with bunding, leveling, irrigation, fertilization and/or line transplanting in Morogoro, Mbeya and Shinyanga. Raes et al. (2007) confirmed in Mtwara and Lindi, Tanzania, that bunding increased rice yield in rainfed lowland fields. Moreover, the authors simulated that the positive effect of bunding is enhanced in soils with a lower percolation rate, suggesting the importance of leveling and puddling for the reduction of percolation. These studies suggest that the low productivity of irrigated rice in Tanzania could be attributed to the absence of a packaged application of basic cultivation techniques, including those used for land improvement, such as bunding and leveling.

The Japanese government started the technical cooperation for rice irrigation in the Kilimanjaro region, Tanzania in the late 1970s (Ikegami 1995). The Kilimanjaro Agricultural Development Centre (KADC), established in 1981, confirmed the effect of packaged application of basic cultivation techniques (Table 1) in a 2.4-ha trial farm and transferred the package to rice farmers in a neighboring 18.9-ha pilot farm. The technical package was further transferred to LMIS constructed in the proximity of KADC and allowed rice farmers there to attain high productivity as described above. The administrative authority of KADC was then transferred from the regional to the national government, and it was renamed to the Kilimanjaro Agricultural Training Centre (KATC). KATC developed the "KATC approach" in an attempt to disseminate the technical package nationally. The KATC approach consists of two major components: (1) joint technical training of farmers and extension officers and (2) farmer-to-farmer (FTF) extension of the technical package (Sekiya et al. 2015b). KATC conducts baseline surveys to collect background information of irrigation schemes, during which the nomination criteria for key farmer (KF) are explained to farmers. A series of technical training (theoretical and practical on-site applications) are provided to both extension officers and KFs in the residential training course. Upon returning to the scheme, KFs and intermediate farmers (IFs) establish a demonstration field in which the KFs transfer the knowledge they gained in the training to the IFs under the guidance of extension officers (in-field training). From 2001 to 2006, KATC tested its approach in six irrigation schemes (Mombo, Mwega, Mbuyuni, Nakahuga, Mwamapuli and Nduguti), and the paddy yield increased from 3.1 to 4.3 t ha^{-1} across the five schemes except in Nduguti where irrigation water was insufficient.

In the present study, we hypothesized that the low productivity of irrigated rice in Tanzania is partly caused

Table 1 Basic cultivation techniques for irrigated rice recommended in the KATC approach

Land preparation	**Fertilizer (top dressing)**
Clearing: 1–2 weeks before plowing	First top dressing: 2 weeks after transplanting
Plowing: 1–2 weeks before puddling	Second top dressing: during panicle initiation
Bunding (or bund repairing)	Amount of fertilizer
Puddling: 1–2 days before transplanting	**Irrigation**
Leveling	Intervals: 5–7 days
Application of organic manure	Important timing 1: weeding
Seedling nursery	Important timing 2: fertilizer application
Raised seedbed	Important timing 3: heading stage
Seedbed levelling	Depth: >3 cm until 1 week before harvesting
Fertilizing of seedbed	Depth: >5 cm during heading
Seed selection	Draining: 1 week before harvesting
Sowing of pre-germinated seeds	**Insect pest and disease**
Sowing rate: approximately 100 g m^{-2}	Cultural control
Irrigation of seedbed: 2–3 day intervals	Chemical control
Transplanting	**Harvest**
Young seedlings: Three week after sowing	Timing: 30–35 days after heading
Number of seedlings per hill: 2–3 seedlings	Yield estimation
Line transplanting	Threshing
Planting density: 30 × 15 cm, 20 × 20 cm	Drying
Gap filling: 1 week after transplanting	Storing
Weeding	
First weeding: 2 weeks after transplanting	
Second weeding: before panicle initiation	

by the absence of the packaged application of basic cultivation techniques. Therefore, we first attempted to determine the extent to which the basic cultivation techniques are practiced in 31 irrigation schemes across the country. Second, we examined the effect of the technical package on the paddy yield in those schemes. These two investigations followed the KATC approach; the practice of the basic cultivation techniques was investigated through farmer interviews during the baseline survey. The effect of the technical package on the paddy yield was examined by providing technical training to farmers in the schemes. Furthermore, we also investigated the extent to which the technical package was disseminated from the KFs to the IFs and then to other farmers (OFs) through the FTF extension.

Materials and methods

Study site

Tanzania, East Africa (1–11°S lat and 28–41°E long; Fig. 2), is a 947,300 km^2 long territory that contains a varied topography, with mountains in the north (including Gregory Rift and Mt. Kilimanjaro), a large plateau (900–1000 m above sea level) in the central, coastal strips in the east, islands in the Indian Ocean (including the Zanzibar Archipelago), and large lakes on the borders (including Lakes Victoria, Tanganyika and Nyasa).

The temperature remains high and relatively constant throughout the year in the lowlands. In Zanzibar, for example, the maximum and minimum temperatures from 2006 to 2008 were 28–35 and 21–25 °C, respectively (Sekiya et al. 2013). However, in the highlands, the high altitudes increase seasonal variations in temperature, making the annual temperature profile more comparable to that in a temperate region than the tropics (Sekiya et al. 2015a); the temperature sometimes falls as low as 10 °C during the cool season from May to September; and the paddy yield is reduced due to the cold-induced sterility.

The rainfall pattern is greatly affected by the migration of the Intertropical Convergence Zone (ITCZ). The ITCZ starts passing over Tanzania from the northeast between October and December and reaches the southwest between January and February. It moves away from the northeast between March and May. This movement causes bimodal rainfall in the northern and eastern regions and unimodal rainfall in the southern, central, and western regions. Bimodal rainfall includes a short-rain season from October to December known locally as "Vuli," and a long-rain season from March to May known as "Masika," and unimodal rainfall has a long-rain season from November or

December to April or May. The annual rainfall varies greatly with the region. The northeastern and central regions receive 200–700 mm. The western and northwestern regions receive 700–1000 mm. The coastal strips and lake areas receive 1000–1400 mm. The wettest locations such as Bukoba district to the west of Lake Victoria, Mbeya district to the north of Lake Nyasa, Kilombero district in the south of Morogoro region, and Zanzibar islands receive 2000–2500 mm and sometimes more than 2800 mm.

A wide variety of parent materials provided by volcanic mountains, the Great Rift Valley, and several plains and mountains with different elevations have been exposed to different temperatures as well as different seasonal distribution and amount of rainfalls, resulting in a wide variety of soil conditions across the country (Funakawa et al. 2012). The soil in the volcanic center of the southern mountain ranging from Mbeya to Lake Nsyasa is very fertile due to the high content of soil organic matter (SOM) and amorphous compounds, and the high availability of phosphorus (P) and potassium (K). The soil around Lake Victoria is also fertile due to the high cation exchange capacity of smectite. In other areas, SOM-related parameters and smectite are generally low probably due to mineral weathering under an ustic soil-moisture regime. Because the proportion of kaolin minerals increases with precipitation, soil fertility in terms of clay mineralogy is relatively low in wet regions. According to Msanya et al. (2002), the major soil types are Ferric, Chromic, and Eutric Cambisols (39.7%) followed by Rhodic and Haplic Ferralsols (13.4%) and Humic and Ferric Acrisols (9.6%). More information is available in Online Resource 1.

KATC approach

The KATC approach (Fig. 1) comprises six important events, beginning with a baseline survey that is followed by residential training before the cropping season; the first, second, and third in-field trainings during the crop growth period; and monitoring and planning after harvest. During residential training, KFs, Village Agricultural Extension Officers (VAEOs) and/or Irrigation Technicians (ITs) from each irrigation scheme are intensively trained on the basic rice cultivation techniques (Table 1), and they are supposed to transfer the knowledge gained to IFs during the three in-field trainings and to OFs on the Field Day. Then, data are compared between the baseline survey and monitoring and planning to evaluate the effect of the trainings on the rice cultivation of each irrigation scheme. In Tanzania, rice cultivation is timed to coincide with the rainy season even under irrigation due to the insufficient water supply for irrigation. Thus, the approach starts well in advance of the rainy season. The KATC approach is described in details in Online Resource 2.

To implement the KATC approach nationally in a relatively short time, three training institutes under the Training Division of the Ministry of Agriculture, Food Security and Cooperatives (MAFC); Ministry of Agriculture Training Institute Ukiriguru (MATI-Ukiriguru) in Mwanza, MATI-Ilonga in Morogoro, and MATI-Igurusi in Mbeya joined KATC as the implementing agency. Zanzibar is a semi-autonomous region in Tanzania, with an administrative unit for agriculture [Ministry of Agriculture Livestock and Environment (MALE), currently referred to as Ministry of Agriculture and Natural Resources (MANR)] independently from the mainland. The Kizimbani Agricultural Training Institute (KATI) under MALE also joined KATC as the agency. The KATC approach was implemented from the 2007/2008 to 2011/2012 cropping seasons in 31 irrigation schemes across Tanzania (Fig. 2; Tables 2, 3). In the 2007/2008 season, the approach was implemented by KATC for the Mahande irrigation scheme, and this was used as a training of trainers (TOT) opportunity for the tutors from MATIs-Ukiriguru, -Ilonga and -Igurusi. Thereafter, the three MATIs also started implementing the KATC approach for irrigation schemes in their charge. The tutors from KATI attended the KATC approach implemented by KATC for the Mussa Mwijanga irrigation scheme, and they implemented it from the 2008/2009 season. KATC, MATIs-Igurusi, -Ilonga, -Ukiriguru and KATI implemented the KATC approach in 5, 10, 8, 5 and 3 irrigation schemes (31 irrigation schemes in total), respectively. The preparatory process of the KATC approach is described in details in Online Resource 2.

Adoption rates of basic cultivation techniques

Toward the end of the 2011/2012 cropping season, the adoption rates of basic cultivation techniques were investigated in Kitivo, Kiloka, Mussa Mwijanga, and Ruanda Majenje irrigation schemes in an attempt to elucidate constraints to the further improvement of paddy yield at the scheme level. We assumed that the FTF extension beyond KFs and IFs is likely to occur as the duration after the implementation of KATC approach lengthens. Then, eight irrigation schemes (Mussa Mwijanga, Kitivo, Ruanda Majenje, Sakalilo, Kiloka, Ilonga, Titye, and Mahiga) were selected where the KATC approach was implemented in the 2008/2009 cropping season (at least three years had passed since the implementation). We again assumed that the adoption rates of basic cultivation techniques are low even in a relatively highly performing scheme (the adoption rates must be increased to further increase the paddy yield at the scheme level). Then, the four irrigation

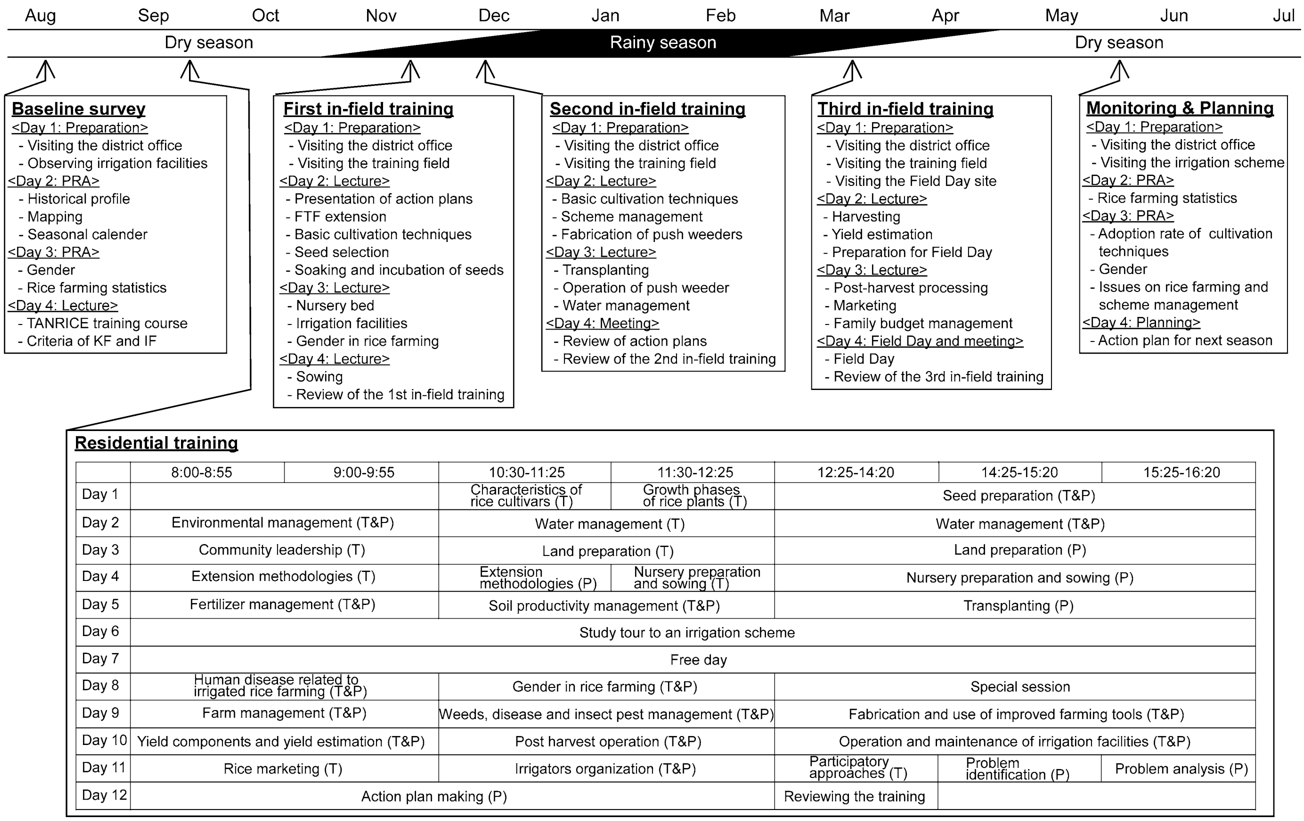
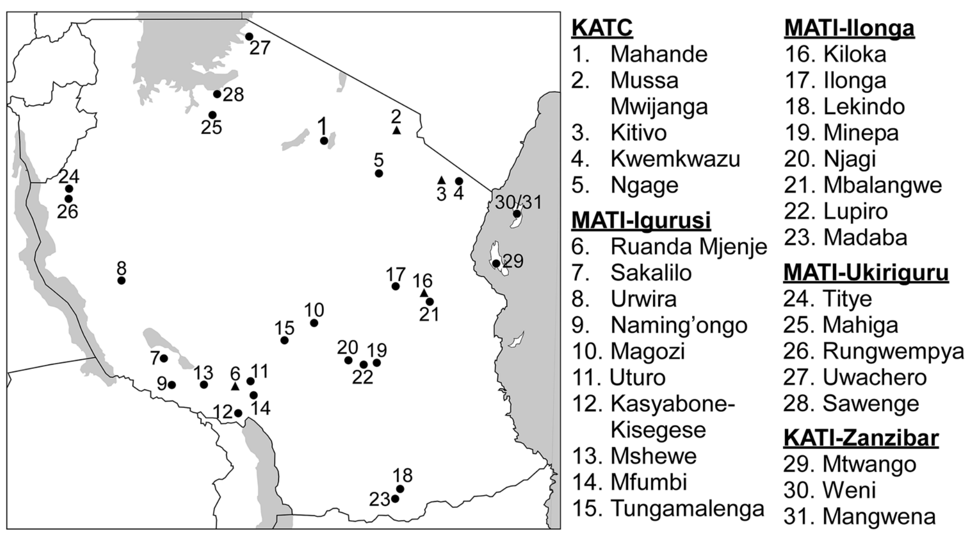


Fig. 1 Schematic diagram of the KATC approach. *FTF* farmer-to-farmer, *IF* intermediate farmer, *KF* key farmer, *P* practical training, *PRA* participatory rural appraisal, *T* theory in class, *TANRICE* Technical Cooperation in Supporting Service Delivery Systems of Irrigated Agriculture

Fig. 2 Locations of irrigation schemes where the KATC approach was implemented



schemes were selected based on their rankings in the paddy yield among the eight schemes. The investigation in each irrigation scheme was conducted for 4 days from May to June in 2012. In this investigation, the adoption rates of only three cultivation techniques (bunding, leveling, and line transplanting) at the scheme level were reported by VAEOs. The three techniques were selected based on their unique characteristics of visibility. Although they are normally practiced during the early stage of rice cultivation, an agronomist like VAEOs can easily recognize their practices on site even after harvesting (in case of line transplanting, one can tell from the arrangement of rice stubbles). In contrast, the practices of the other techniques except planting density (Table 1) are difficult to confirm

Table 2 Area, number of farmers, and degree of practice of seven basic cultivation techniques for irrigated rice in 31 irrigation schemes in Tanzania

MATI	Scheme (District, region)		Area (ha)	Number of farmers	Degree of practice (%)						
					Bunding	Leveling	Seed selection	Raised seedbed	Young seedlings	Line transplanting	Chemical fertilizer
KATC	1	Mahande (Monduli, Arusha)	142	275	–	–	20	90	–	0	50
	2	Mussa Mwijanga (Hai, Kilimanjaro)	285	420	50	50	–	–	0	100	100
	3	Kitivo (Lushoto, Tanga)	500	1248	10	20	0	30	0	40	20
	4	Kwemkwazu (Lushoto, Tanga)	120	316	0	0	80	80	15	2	0
	5	Ngage (Simanjiro, Manyara)	214	215	0	0	75	90	0	95	95
Igurusi	6	Ruanda Majenje (Mbarali, Mbeya)	180	174	40	5	–	–	0	1	20
	7	Sakalilo (Sumbawanga, Rukwa)	200	67	40	40	–	–	1	0	0
	8	Urwira (Mpanda, Rukwa)	240	138	5	100	0	5	0	0	0
	9	Naming'ongo (Mbozi, Mbeya)	1500	630	20	10	–	–	1	0	0
	10	Magozi (Iringa, Iringa)	1500	4020	90	40	–	–	1	0	0
	11	Uturo (Mbarali, Mbeya)	338	142	5	30	5	15	0	5	34
	12	Kasyabone-Kisegese (Rungwe, Mbeya)	470	767	20	5	10	0	0	0	5
	13	Mshewe (Mbeya, Mbeya)	100	72	–	40	–	–	0	–	20
	14	Mfumbi (Makete Iringa)	160	167	0	0	69	69	0	30	40
	15	Tungamalenga (Iringa, Iringa)	525	176	3	5	5	75	0	0	98
Ilonga	16	Kiloka (Morogoro, Morogoro)	80	196	0	0	10	5	10	10	10
	17	Ilonga (Kilosa, Morogoro)	600	250	5	1	5	5	1	1	95
	18	Lekindo (Tunduru, Ruvuma)	100	204	4	2	4	2	0.5	2	90
	19	Minepa (Ulanga, Morogoro)	150	–	–	–	–	–	–	–	–
	20	Njagi (Kilombero, Morogoro)	375	250	0	1	100	5	10	10	20
	21	Mbalangwe (Morogoro, Morogoro)	500	76	0	0	0	0	0	0	0
	22	Lupiro (Ulanga, Morogoro)	2500	950	20	90	100	90	3	10	80
	23	Madaba (Tunduru, Ruvuma)	600	251	0	0	0	0	0	1	95
Ukiriguru	24	Titye (Kasulu, Kigoma)	140	714	70	30	0	0	0	0	0
	25	Mahiga (Kwimba, Mwanza)	80	141	25	25	0	0	10	20	0
	26	Rungwempya (Kasulu, Kigoma)	150	150	0	0	0	0	0	0	0
	27	Uwachero (Rorya, Mara)	120	300	75	11	85	85	0	60	67
	28	Sawenge (Magu, Mwanza)	150	94	50	23	0	0	0	0	0
KATI	29	Mtwango (Unguja)	82	417	0	90	15	50	16	100	100
	30/31	Weni/Mangwena (Pemba)	26	179	50	0	98	0	38	82	100
Total/mean			12,127	12,999	21.6	22.1	29.6	30.3	3.8	20.3	39.3

without interviewing all farmers. Due to the limited amount of financial and human resources available, the adoption rates were investigated by observing the three cultivation techniques on site instead of interviewing 2038 farmers across the four irrigation schemes. After receiving reports from VAEOs, the tutors interviewed 10 KFs, 20 IFs, and 80–100 OFs previously selected by the VAEOs and scheme manager individually. Each farmer provided information about the personal attributes (Online Resource 3) and adoption of three basic rice cultivation techniques in their fields. Then, each of the KFs and IFs was individually asked how they transferred the technical knowledge to their subordinates, and each of the OFs was asked from whom they obtained the technical knowledge. After the interview, the tutors visited several fields of randomly selected OFs to compare the actual condition of fields with the information provided by the OFs at the time of interview. In addition, the tutors made a short trip within the irrigation scheme and interviewed 10 farmers working in their fields.

Results

Practice of the basic cultivation techniques before the KATC approach

Table 2 shows a summary of rice farming statistics in the 31 irrigation schemes before the implementation of the KATC approach. A wide variation in size and population of irrigation schemes was noted in this study, ranging from 26 to 2500 ha and from 67 to 4020 farmers, respectively. In total, the studied area was 12,127 ha in which 12,999 farmers cultivated rice fields. The degree of practice of basic cultivation techniques was represented by seven techniques instead of showing all the data of 37 techniques. The two land preparation techniques, bunding and leveling, were responsible for water storage in rice fields. The area of bunded and leveled fields over the entire area of each irrigation scheme ranged from 0 to 90% and from 0 to 100%, respectively. On average, the bunded and leveled fields were 21.6 and 22.1%, respectively. The two seedling nursery techniques, seed selection and raised seedbed, allowed the establishment of uniformly grown, healthy seedlings. The percentage of farmers who selected well-filled seeds and saw seeds in raised seedbeds in each irrigation scheme ranged from 0 to 100% and from 0 to 90%, respectively. On average, 29.6 and 30.3% of farmers practiced seed selection and raised seedbeds, respectively. The two transplanting techniques, young seedlings and line transplanting, allowed rice plants to grow vigorously in fields. The percentage of farmers who transplanted seedlings 3 weeks after sowing in each irrigation scheme ranged from 0 to 38%, whereas the area of line-transplanted fields over the entire area of each irrigation scheme ranged from 0 to 100%. On average, 3.8% of farmers transplanted young seedlings and 20.3% of fields were line-transplanted. The application of chemical fertilizers enhanced plant growth; 0–100% of farmers applied chemical fertilizer in each irrigation scheme with an average of 39.3%.

Effect of the KATC approach on paddy yield

The paddy yields before and after the implementation of the KATC approach in each of the 31 irrigation schemes were compared (Table 3). Out of 31 irrigation schemes, 24 schemes increased the paddy yield after receiving the KATC approach. A remarkable increase in the paddy yield was observed in the Mahande, Lekindo, Mbalangwe and Rungwempya irrigation schemes. The paddy yield in those schemes became 2.1–4.3 times higher after the KATC approach. In the Kitivo, Kiloka and Lekindo irrigation schemes, the great increment of the paddy yield was achieved through the introduction of double cropping. In contrast, the remaining seven irrigation schemes did not increase or even reduced the paddy yield after the KATC approach. Overall, the mean paddy yields across the 31 irrigation schemes were 2.4 and 3.6 t ha^{-1} year^{-1} before and after the implementation of the KATC approach, respectively. The increment of the mean paddy yield was tested by paired *t* test to be significant at 1% level.

Adoption rates of basic cultivation techniques

The degree of practice of the three cultivation techniques at the scheme level was compared before and after the implementation of the KATC approach (Table 4). The area of bunded, leveled, or line-transplanted fields increased in each of the four irrigation schemes one to two years after the KATC approach. This indicates that the KATC approach encouraged a number of farmers to adopt each of the three techniques. However, the adoption rate varied with cultivation technique and irrigation scheme. For example, the line-transplanted fields spread across the entire scheme in Musa Mwijanga, Kitivo, and Kiloka but covered only 5% of the scheme in Ruanda Majenje. Unlike line transplanting, the area of bunded or leveled fields reached only 50–75% of the entire scheme. Overall, the adoption rates were 56, 56 and 76% for bunding, leveling, and line transplanting across the four schemes.

The degree of practice of the three cultivation techniques at the farmer level after the implementation of the KATC approach was also investigated (Table 5). In the Mussa Mwijanga and Kitivo irrigation schemes, each of the three techniques was adopted well by all the three classes of farmers (100%) except leveling of KFs in Mussa

Table 3 Paddy yield before and after implementation of the KATC approach in 31 irrigation schemes

Training institute	Scheme (training season)		Cropping pattern	Yield (t ha^{-1} season^{-1})					Mean annual yield (t ha^{-1} year^{-1})	
				06/07	07/08	08/09	09/10	10/11	Pre	Post
KATC	1	Mahande (07/08)	Single	*1.6*	n.a.	2.9	4.9	3.9	*1.6*	3.9
	2	Mussa Mwijanga (08/09)	Double		*2.6*	n.a.	3.2	4.2	*2.6*	3.7
					3.8	n.a.	3.2	4.8	*3.8*	4.0
	3	Kitivo (08/09)	Double		*2.9*	5.1	5.3		*2.9*	5.2
							4.2		*0*	4.2
	4	Kwemkwazu (10/11)	Single			*2.6*	*2.6*	3.6	*2.6*	3.6
	5	Ngage (11/12)	Double				*2.6*	3.2	*2.6*	3.2
							2.4	3.6	*2.4*	3.6
Igurusi	6	Ruanda Majenje (08/09)	Single	*2.6*	*3.4*	3.4	3.8		*3.0*	3.6
	7	Sakalilo (08/09)	Single		*4.1*	4.6	3.4		*4.1*	4.0
	8	Urwira (09/10)	Single			*1.7*	1.7	1.5	*1.7*	1.6
	9	Naming'ongo (09/10)	Single			*1.3*	2.6	1.8	*1.3*	2.2
	10	Magozi (09/10)	Single			*4.0*	3.4	4.1	*4.0*	3.8
	11	Uturo (09/10)	Single			*2.9*	4.5	5.8	*2.9*	5.2
	12	Kasyabone-Kisegese (10/11)	Single			*2.0*	*1.3*	1.0	*1.7*	1.0
	13	Mshewe (10/11)	Single			*1.3*	*2.1*	2.0	*1.7*	2.0
	14	Mfumbi (10/11)	Single			*2.4*	*3.2*	4.0	*2.8*	4.0
	15	Tungamalenga (10/11)	Single			*2.0*	*2.2*	2.8	*2.1*	2.8
Ilonga	16	Kiloka (08/09)	Double		*2.4*	4.0	5.0		*2.4*	4.5
						3.2	2.0		*0*	2.6
	17	Ilonga (08/09)	Double		*2.0*	5.3	2.1		*2.0*	3.7
					1.6	3.2	1.6		*1.6*	2.4
	18	Lekindo (09/10)	Double		*2.0*	*1.4*	3.7	3.5	*1.7*	3.6
								1.9	*0*	1.9
	19	Minepa (09/10)	Single			*2.0*	1.6	4.4	*2.0*	3.0
	20	Njagi (09/10)	Double			*3.0*	4.9	6.9	*3.0*	5.9
						2.4	3.0	3.8	*2.4*	3.4
	21	Mbalangwe (10/11)	Single			*1.3*	*1.3*	4.5	*1.3*	4.5
	22	Lupiro (10/11)	Single			*5.2*	*3.9*	5.5	*4.6*	5.5
	23	Madaba (10/11)	Single			*2.5*	*2.7*	4.3	*2.6*	4.3
Ukiriguru	24	Titye (08/09)	Single	*2.0*	*2.0*	3.0	2.0		*2.0*	2.5
	25	Mahiga (08/09)	Single	*1.5*	*2.2*	n.a.	3.0	0.8	*1.9*	1.9
	26	Rungwempya (09/10)	Single			*1.0*	5.6	3.0	*1.0*	4.3
	27	Uwachero (10/11)	Single				*5.4*	6.0	*5.4*	6.0
	28	Sawenge (10/11)	Single			*2.3*	*4.5*	1.8	*3.4*	1.8
KATI	29	Mtwango (09/10)	Single		*5.0*	*4.0*	6.0	6.0	*4.5*	6.0
	30	Weni (10/11)	Single			*3.2*	*1.6*	4.0	*2.4*	4.0
	31	Mangwena (10/11)	Single			*2.0*	*3.2*	2.0	*2.6*	2.0
Mean									*2.4*	3.6

Each value in the "Yield" columns indicates the paddy yield recorded in each irrigation scheme during a single cropping season. There are two values in a single cropping season for those irrigation schemes growing rice twice a year (double cropping). The underlined value in Italic letters and that in standard ones indicate the paddy yield before and after the KATC approach, respectively. "Pre" and "Post" indicate the mean annual yield before and after the KATC approach, respectively. Each training institute implemented the KATC approach for irrigation schemes in its charge. *KATC* Kilimanjaro Agricultural Training Centre, *KATI* Kizimbani Agricultural Training Institute

Table 4 Degree of practice of bunding, leveling, and line transplanting at the scheme level in Musa Mwijanga, Kitivo, Ruanda Majenje, and Kiloka irrigation schemes before and after implementation of the KATC approach

Scheme	Before/after the KATC approach (cropping season)	Degree of practice (%)		
		Bunding	Leveling	Line transplanting
Mussa Mwijanga	Before (08/09)	50	50	100
	After (10/11)	75	75	100
Kitivo	Before (08/09)	10	20	40
	After (10/11)	50	50	100
Ruanda Majenje	Before (08/09)	40	5	1
	After (10/11)	50	50	5
Kiloka	Before (08/09)	0	0	10
	After (10/11)	50	50	98
Mean	Before	25	19	38
	After	56	56	76

Degree of practice is the percentage of field area applied with each cultivation technique over the entire area of each irrigation scheme. All fields were surveyed in each irrigation scheme (see Table 2 for the entire area of each scheme)

Table 5 Degree of practice of bunding, leveling, and line transplanting at the farmer level in Musa Mwijanga, Kitivo, Ruanda Majenje, and Kiloka irrigation schemes after implementation of the KATC approach

Scheme	Farmer class	Number of farmers	Adoption rate (%)		
			Bunding	Leveling	Line transplanting
Mussa Mwijanga	KF	8	100	86	100
	IF	14	100	100	100
	OF	53	100	100	100
Kitivo	KF	10	100	100	100
	IF	20	95	100	100
	OF	62	100	100	100
Ruanda Majenje	KF	10	100	100	30
	IF	13	100	100	8
	OF	81	93	83	20
Kiloka	KF	7	100	100	100
	IF	15	100	100	100
	OF	106	85	91	91
Mean	KF	35	100	97	83
	IF	62	99	100	77
	OF	302	95	94	78

Adoption rate is the percentage of farmers practicing each cultivation technique in each irrigation scheme

Mwijanga (86%) and bunding of IFs in Kitivo (95%). In the Ruanda Majenje irrigation scheme, the two techniques, bunding and leveling, were adopted well by KFs and IFs (100%) but relatively poorly by OFs (93 and 83% for bunding and leveling, respectively). In contrast, the line transplanting technique was adopted poorly by all the three classes of farmers (30, 8 and 20% in KFs, IFs and OFs, respectively). In the Kiloka irrigation scheme, each of the three techniques was adopted well by KFs and IFs (100%) but relatively poorly by OFs (85, 91 and 91% for bunding, leveling, and line transplanting, respectively). Overall, the technical adoption rate was higher in KFs (83–100%) and IFs (77–100%) than in OFs (78–95%).

In the KATC approach, KFs and IFs were requested to transfer their technical knowledge to OFs during either regular training or field day (Table 6). Although some KFs and IFs in the Kitivo (3–21%), Ruanda Majenje (0–15%) and Kiloka (4–21%) irrigation schemes used the two official occasions for the technical transfer, most KFs and IFs transferred the knowledge to OFs when they visited OFs (20–67%) or they were visited by OFs (20–37%) across the four irrigation schemes.

Table 6 Occasions of technical transfer from KFs and IFs to OFs in Musa Mwijanga, Kitivo, Ruanda Majenje, and Kiloka irrigation schemes

Scheme	Farmer class	Regular training	Field day	When visited by	When visited to	Others	No transfer
Mussa Mwijanga	KF	0	0	33	67	0	0
	IF	5	0	36	59	0	0
Kitivo	KF	21	14	31	35	0	0
	IF	6	3	23	54	14	0
Ruanda Majenje	KF	15	8	35	31	12	0
	IF	0	0	20	20	0	60
Kiloka	KF	21	5	32	32	11	0
	IF	11	4	37	44	4	0
Mean	KF	14	7	33	41	6	0
	IF	6	2	29	44	5	15

Each value is the percentage of farmers using each occasion in each irrigation scheme. The number of farmers interviewed should be referred to Table 5. The technical transfer occurred during the 2009/2010, 2010/2011, and 2011/2012 cropping seasons

Table 7 Technical information sources from whom OFs obtained each of bunding, leveling, and line transplanting techniques in Musa Mwijanga, Kitivo, Ruanda Majenje, and Kiloka irrigation schemes

Scheme	Bunding				Leveling				Line transplanting			
	VAEO	KF	IF	Other	VAEO	KF	IF	Other	VAEO	KF	IF	Other
Mussa Mwijanga	13	49	26	11	14	50	30	6	13	38	45	4
Kitivo	22	41	30	6	23	33	33	11	23	32	34	11
Ruanda Majenje	34	28	23	15	23	37	27	13	39	39	17	6
Kiloka	15	38	43	5	14	36	44	6	16	32	49	3
Mean	21	39	31	9	19	39	34	9	23	35	36	6

Each value is the percentage of farmers receiving technical information from each information source. Since some farmers received technical information from multiple sources, the percentage was calculated by dividing the number of farmers receiving technical information from each information source by the total number of answers

Furthermore, the source of technical information for OFs was investigated (Table 7). In the KATC approach, OFs should learn basic cultivation techniques from either KFs or IFs. Indeed, KFs and IFs were the major information source of bunding (23–49%), leveling (27–50%) and line transplanting (17–49%) for OFs across the four irrigation schemes. However, a substantially high percentage of OFs obtained technical information of bunding (13–34%), leveling (14–23%) and line transplanting (13–39%) from VAEOs across the four schemes.

Discussion

The baseline survey conducted in the 31 irrigation schemes revealed that a large proportion of irrigated rice fields in Tanzanian are cultivated without the application of basic cultivation techniques (Table 2). The percentage of farmers transplanting young seedlings was particularly low, and in 21 schemes, no farmers practiced it. The transplanting of young seedlings lengthens the growth duration in the field and increases the paddy yield through early and high tiller production (Pasuquin et al. 2008). However, many farmers transplanted their seedlings 30–40 days, and sometimes 50 days after sowing. Although approximately 30% of farmers practiced the both seed selection and nursery making, the effort may have become ineffective due to the extended duration of seedlings in the nursery. Then, only approximately 20% of the farmers practiced bunding and leveling. During the survey, many farmers reported that water shortage was one of the major constraints in their farming. The absence of good bunds and leveled soils may have wasted the limited water and further worsened the water shortage problem (Raes et al. 2007). The percentage of farmers practicing line transplanting was as low as 20%. The randomly sown or transplanted plants may have negatively affected efficient weeding, and thus induced competition with rice plants for limited water and nutrients (de Datta and Bernasor 1973; Rao et al. 2007). In contrast, a relatively large percentage of farmers (>40%) applied chemical fertilizer. The positive effect of chemical fertilizer on the crop growth including rice (Meertens et al.

2003) is largely recognized by farmers in Tanzania due to the implementation of public and private extension services (Rutatora and Mattee 2001; Mvuna 2010). Indeed, almost all the farmers reported their knowledge about chemical fertilizer during our baseline survey. The government subsidies on agricultural input that was newly introduced during our study also made chemical fertilizer more accessible to farmers. However, the full potential of chemical fertilizer may have been lost due to inappropriate watering and growth management as above.

It was inferred from the present study that the packaged application of basic cultivation techniques alone could have a significant impact on the productivity of irrigated rice without a large investment on irrigation facilities (Table 3). Recently, Nhamo et al. (2014) proposed that the combined application of existing cultivation techniques such as the weed control, chemical fertilizer, manure, bunding and improved cultivar should increase the productivity of rice cultivation in East and Southern African regions. Their suggestion of using locally available technology and resources is in agreement with our study. While they emphasized the introduction of improved cultivars, our farmers increased the paddy yield without investing in this. Otsuka and Kijima (2010) argued that the productivity of rice cultivation in sub-Saharan Africa could be greatly increased by the introduction of rice cultivation techniques from Asia. This was based on the observation of high-yielding rice farming in LMIS, Tanzania, and the Mwea irrigation scheme, Kenya, where the Japanese government introduced basic cultivation techniques of irrigated rice after the construction of modern irrigation facilities. Indeed, in West Africa, the *sawah* system was introduced from tropical Asia (Abe and Wakatsuki 2011), and was proven effective at increasing the paddy yield in inland valleys in Ghana (Asubonteng et al. 2001; Ofori et al. 2005) and Nigeria (Nwite et al. 2008; Obalum et al. 2011). While the system is characterized as the leveled and puddled basin surrounded by bunds, it also involves some basic cultivation techniques such as line transplanting of young seedlings and the application of chemical and organic fertilizers. The *sawah* system emphasizes the importance of land preparation as it is regard as a prerequisite for rice irrigation; many rice fields in sub-Saharan Africa are cultivated without it. Importantly, the *sawah* system depends on locally available resources rather than a large investment that is beyond the reach of small-scale farmers. Thus, the underlying concept of the *sawah* system is very similar to that of our basic cultivation techniques. In the present study, however, the effect of packaged application of basic cultivation techniques on the productivity of irrigated rice was evaluated by simply comparing the two paddy yields before and after the technical training within the same irrigation scheme (Table 3). This analysis might have been biased with confounding variables such as cultivar, fertilizer rate, water supply and farmer capacity. In the future study, therefore, a randomized experiment using a statistical matching technique should be employed to estimate the effect more clearly.

The post-training paddy yield of 3.6 t ha^{-1} was still lower than 4.3–8.1 t ha^{-1} in the cultivar selection trials (Kanyeka et al. 2004) and 4.6–8.4 t ha^{-1} in LMIS (Ikegami 1995). We hypothesized that this discrepancy is caused by low adoption rates of basic cultivation techniques at the scheme level. Then, the farmer interview was conducted after the implementation of KATC approach to have some implications for the hypothesis. In all the four irrigation schemes surveyed, each of the three techniques: bunding, leveling, and line transplanting diffused after the technical training (Table 4). However, none of the three techniques could cover the entire area of any of the four schemes except for the line transplanting in Musa Mwijanga and Kitivo, indicating the presence of factors inhibiting the technical diffusion (Table 4). The farmer interview indicated that the technology adoption was relatively low at the OF level (Table 5). Sekiya et al. (2015b), who investigated the extent to which the KATC approach disseminated a new rice cultivar NERICA1 in Tanzania, concluded that no intervention on the technical transfer beyond KFs and IFs causes the low adoption of the cultivar in OFs. Indeed, in the present study, MATIs made no intervention on OFs except the exhibition of the demo-field at the Field Day. The separate interview with KFs and IFs revealed that they transferred the techniques to OFs during ordinary, mutual visitation rather than through the framework requested by MATIs (Table 6). This is probably because few incentives exist for KFs/IFs to take the time to create an official occasion for the technical transfer, and in addition, the essence of techniques can be conveyed easily with the face-to-face, repeated, practical training on site rather than official group learning. Further interviews with OFs indicated that VAEOs also played a significant role in the technical adoption at the OF level (Table 7). These results suggest that the technical transfer of the three techniques beyond KFs and IFs does not occur through the pre-determined framework but as a result of the interaction among farmers, and is supplemented by VAEOs where necessary. Therefore, the factors inhibiting the technical diffusion of the three techniques at the scheme level in the four schemes could be as follows; (1) the time-consuming FTF extension was unable to cover the entire scheme within the short time between the technical training and the farmer interview, and (2) the work of VAEOs was insufficient to supplement the FTF extension. It was inferred from this farmer interview that the adoption rates of 37 basic cultivation techniques were also low at the scheme level in the 31 irrigation schemes, making the post-training yield low compared with those of cultivar selection trials and LMIS. Thus, it might be necessary to further intervene in the post-training process of technical dissemination for the further improvement of paddy yield.

Conclusion

The absence of a packaged application of basic cultivation techniques could be the cause of the low productivity of irrigated rice in Tanzania. Although the mean paddy yield across the 31 irrigation schemes increased greatly, the value still remained low compared with high-yields recorded in the cultivar selection trials and LMIS. This discrepancy could be partly due to insufficient technical diffusion in each irrigation scheme attributable to the time-consuming nature of the FTF extension that gradually occurs through the day-to-day interactions among farmers. The provision of more support for VAEOs might enhance the technical diffusion considering their supplemental role in the FTF extension.

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