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The Adoption of the Latin American Rice Production System through the Implementation of Advanced Field Management Practices: An Evaluation of Technology Adoption Patterns and the Impact on Yield in Colombia

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The Colombian National Federation of Rice Growers promotes technological development, economic efficiency, and increased competitiveness by implementing a massive technology adoption (AMTEC) program on rice production. K–means clustering was used to determine the number of the combinations (technology package) of the eight specified AMTEC technologies (vibrating chisel ploughs, land plane levelers, taipa, pre–fertilization, certified seeds, drill sowing, sowing density, and continuous irrigation) adopted by rice farmers and regression analysis was employed to determine the impact of the adoption of specific technology on yield. The results indicated that there were 162 AMTEC technology combinations (technology packages) applied across 11,007 rice famers under an irrigated system. On an average, the number of implemented AMTEC technologies across each combination was 4.8. The usage of tools and techniques in land preparation such as vibrating chisel ploughs and pre–fertilization. Sowing techniques such as drill sowing, coupled with the usage of certified seeds were the most adopted technologies by farm clusters with the highest yields. On the contrary, tools and technologies such as land plane levelers and taipa that are utilized in land preparation were less commonly adopted. The results also highlighted the positive effect of the adoption of drill sowing and the usage of certified seeds on paddy yield.

Key words: impact, K–means clustering, technology adoption, technology packages, technology transfer

1 INTRODUCTION

While a free trade agreement (FTA) between Colombia and the United States was being negotiated, the government in consultation with the representatives of agricultural producers, agreed to design and implement a program with the aim of compensating the losers of the agreement and enhancing sectorial competitiveness. A program was thus launched in April of 2007 in keeping with these objectives, and was allocated substantial operational resources (Argüello and Valderrama–Gonzalez, 2015). This policy package appears to reinforce a policy trend in Colombia, namely increased transfers to agricultural producers. As a result, Colombia became the highest level of transfers per person engaged in agriculture among the Latin American. The estimated area of rice production in Colombia is 570,802 hectares benefiting 210 rice municipalities, with a 4% share of agricultural production to the gross domestic product (GDP) (FEDEARROZ, 2017).

The rice sector was however, characterized by two simultaneously occurring phenomena (Torres, 2013): 1) A reduction in the price of rice for farmers, which is driven by a downward pressure in prices brought on by the FTA with the United States and by the implementation of an agreement with industries regarding price ranges, 2) A decline in rice yields as a result of climatic variability (as determined by factors such as the maximum and minimum temperatures, luminosity, rainfall distribution, and relative humidity) and the presence of pathogens. Considering the need to increase competitiveness, the National Federation of Rice Growers (FEDEARROZ) proposed a program to facilitate a massive adoption of technology (the program is known as AMTEC, which is its acronym in Spanish). This program is characterized by a model for technology transfer based on sustainability and social responsibility that tends to foster the interests of a rice sector, promote competitiveness, and improve the profitability of producers. With the implementation of this program came a massive integration of technology during the period 2012– 2017. It aims to implement production technologies that facilitate an increase in productivity and reduce production costs and at the same time, foster the adoption of the best cropping practices for environmental preservation, which invariably affects the sustainability of the crop, thereby reducing the impact of phenomena such as climate change. Therefore, from 2018, a second version of the program was implemented and termed as AMTEC 2.0, with the inclusion of new agricultural tech-

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nologies such as precision agriculture, the incorporation of agro–climatic services, coupled with accounting for the environmental impact of agriculture. By combining new technological variants with the attainment of a high degree of efficiency in the usage of water and other resources such as fertilizers, and with the adoption of resource saving crop management practices, coupled with the implementation of a decision support system and precision agriculture using advanced information technology (IT) and sensing technology as recommended under the AMTEC program, productivity under any cultivation conditions across Colombia is expected to be enhanced, with the country potentially attaining self–sufficiency in rice production.

However, there are a scarce number of studies that concern the analysis of the impact of adoption patterns for technological combinations on the rice production system. Li *et al*. (2008) highlighted that an increase in the number of bundled technologies and increases in hog production were likely to complement one another, thereby suggesting that farmers have an incentive to simultaneously adopt a multitude of technologies. The complementarity among technologies in large bundles was contributing to a form of returns to scale that was leading to increased growth in the average farm size.

Lambert *et al*. (2015) in their study of the bundling of technologies in precision agriculture found that there were 154 technology combinations (technology packages) utilized by cotton producers. Cotton producers tend to apply a single technology, thereby implying that the usage of full sets of multiple technologies across precision agriculture was very rare. Studies have depicted that technological intervention in rice production in sub–Saharan Africa can result in an increase in yield, if adopted in conjunction with the technology that was adopted for rice production in the Asian continent, given their strong complementarities (deGraft–Johnson *et al*., 2014). Faltermeier and Abdulai (2009) emphasized that the full dissemination of technology can improve the productivity and profitability of rice farming in sub–Saharan Africa. The implementation of combined technology such as seeds and fertilizers is found to increase demand and affect the degree of adoption of interrelated technology.

This study analyzes the adoption of information and processing technologies that are associated with the AMTEC program based on the 4th Colombia National Rice Census 2016 (FEDEARROZ, 2017). The focal point of the research is the impact and effect of AMTEC technology on productivity. The specific research objectives of this study are: (1) to describe the characteristics of Colombian rice producing unit (RPU) and adaptation of AMTEC technology on that RPU, specifically with regard to total 20,174 RPUs, (2) to determine the number of the combinations of the eight specified AMTEC technology elements adopted by farmers and their patterns, and (3) to determine the impact of the implemented AMTEC technology on yield in the case of 11,007 RPUs under the irrigated system in Colombia.

2 METHODOLOGY

2.1 Data

The data utilized in the analysis conducted in this study were collected from the 4th Colombia National Rice Census 2016 (FEDEARROZ, 2017) for 20,174 RPUs in second half of the cultivation season (from July 1 to December 31) in 2016. The survey was conducted by FEDEARROZ and the National Administrative Department of Statistics (DANE) in Colombia. The objective of this survey is to update the available basic and national wide information on the Colombian rice sector and evaluate the impact during the first five years of the implementation of the AMTEC program. The FEDEARROZ decided to conduct the analysis by dividing five rice cultivation regions based on geographical conditions into two categories, namely irrigated and non–irrigated. This study covers the analysis of the adoption patterns of various combinations of eight AMTEC technology elements and evaluates the impact mainly on irrigated RPUs, since rice production relies heavily on irrigation. Following the survey, the nationwide yield under an irrigated system was 60% higher than that with a non–irrigated system. The data set utilized in cluster analysis and regression analysis in this study pertains to 11,007 RPUs under an irrigated system.

2.2 AMTEC in Colombia rice production system

The AMTEC program is based on principle parameters such as: *Diagnosis*, which covers the analysis of historical farm data, farm production processes, and farm economics; *Planning*, which includes the analysis of economic, financial, and agronomic aspects; *Agronomic management*, which focuses on planting time management and the selection of varieties that are suitable for specific seasons and sites; *Soil analysis*, which encompasses the study of physical, chemical, and biological soil components; *Soil preparation and conditioning*, which provides guidance on land leveling, mud levees usage, and drainage construction. Other parameters included in the study are the construction of reservoirs, storage canals, ditches, irrigation, drainage, and efficient water use. Furthermore, the cultivation of crops, the utilization of planters for minimal tilling, the impact of low sowing densities, and the monitoring of plant population growth were also studied. *Water management* methods are adopted to reduce the size of properties to enhance irrigation efficiency, to incorporate the appropriate intrapredial irrigation technology and to sustain humid conditions. The development of a *balanced and timely nutrition plan* suggests the understanding of the physiology of the plant in order to nourish it according to its development in a timely and balanced way, in keeping with the underlying environmental conditions deciphered through soil analysis and the usage of a web platform to make recommendations. *Phytosanitary monitoring and management* involves the analysis of initial weed populations and early intervention with the utilization of the appropriate techniques, coupled with

Table 1. A description of eight AMTEC technology elements

AMTEC Technology	Description
Land Preparation	
Vibrating Chisel Plough (VCP)	A vibrating chisel plough is a very economical way to quickly carry out a deep tillage operation. It has a relatively low initial cost compared to other tools. It has the ability to till one seedbed at a time. It can be adjusted to carry out a deep or a shallow tilling operation and it does not alter the soil profile. The chisel plough performs the initial loosening of the soil while leaving the top layer. The depth is usually set between 18 cm to 25 cm. The maximum depth is 37 cm. Plow tillage also extracts organic matter by building on the soil.
Land Plane Leveler (LP)	There are several ways to compute the new field slope including certain inspection methods that required some experienced judgment. A formal method, called the 'plane method,' will be used here. The plane method utilizes a simple least squares or linear regression model to fit field elevations to a two–dimensional plane. Subsequent adjustments are made in the elevation of the plane centroid to compensate for varying cut/fill ratios (http://www.fao.org/).
Taipa (TP)	*Taipa* is an equipment utilized in the construction of relatively low levee bunds without a deep depression to hold the irrigated water within the plot. Local farmers construct contour levees with a height of approximately 12 cm, along the contour lines. The recommended contour–levee construction enables farmers to sow over the entire plot directly, including the top part of contour levees by dry–seeding machines, so that the spatial uniformity of rice growth is relatively maintained. The basic practices of a contour–levee irrigation system was summarized by Pineda and Montaña (2015). This technique was applied to achieve efficiency in the usage of water and fertilizers.
Pre–fertilization (PF)	In order to understand the physiology of the plant, prior to the fertilization phase, soil analysis was undertaken in each farm. Pre–fertilization is the application of basal fertilizers such as KCl, DAP (Phosphoric acid), Diammonium Phosphate (DAP), Chloride Potassium (KCL), Sulfate Zinc (Zn), Sulfate Iron (Fe) and Minor Nutrition, Borax (B). Farmers with a manual or direct sowing method applied pre–fertilization during soil preparation. For farmers who undertook the transplant sowing method, pre–fertilizer was implemented one or two days prior to the commencement of transplanting. This practice is associated with the timely management of weeds.
Sowing	
Certified seed (CS)	The use of certified seeds approved by the ICA, must meet the following conditions: Pure seed (minimum) 99%, inert material (maximum) 1.0%, seeds of other varieties (maximum) 50 seeds / kg, seeds of other crops (maximum) 3 seeds / kg, common weed seeds (maximum) 3 seeds / kg, noxious weed seeds (maximum) 2 seeds / kg, weed seeds forbidden (maximum) 0 seeds / kg, diseases transmitted by seed 0, humidity (maximum) 14%, germination (minimum) 80%, red rice seed (maximum) 1 seed / kg (Reference: Resolution 003168 of September 7, 2015, ICA).
Drill sowing (DS)	Direct sowing of dry–seeds to the soil by utilizing a calibrated seed drill. In general, the application of fertilizers that is undertaken at the same time depends on the soil conditions.
Sowing density less than 150 kg/ hectare (SD)	A seed density of less than 150 kg is required in order to achieve a good crop yield, which depends on the population of the optimal plant. The population of plants refers to the minimum number of plants per unit area that guarantee a high yield.
Irrigation system	
Continuous Irrigation (CI)	A gravitational irrigation method for sloped fields which is characterized by the intermittent application of water with an interval of 3–5 days at the top of the plot to fill the end of plot (this timeline applies to an average plot size of 2–20 ha). The irrigated water can be easily drained from the plot and can be repeatedly applied to alternative wet and dry soil conditions. In general, the local farmers prepare contour levee using taipa to retain the water for lowland rice cultivation. This method can be modified for any soil conditions to achieve efficiency in the utilization of water resources and low costs. In addition, the ability to control the application of water to fields is critical, especially after applying fertilizer, so that vital nutrients are not lost or to drain the field for harvest.

Source: FEDEARROZ (2017)

the management of phytophagous insects and diseases through biological controls, monitoring during key seasons to estimate plant population levels, and the usage of chemical controls based on action thresholds.

We categorized the eight AMTEC technology elements as specified in the 4th Colombia National Rice Census 2016 (FEDEARROZ, 2017) and implemented these into the land preparation and sowing processes, and into the irrigation system. Each AMTEC technology element that is discussed in this study is presented in Table 1. The technology elements were used either during the dry land pre–sowing or planting phases. The four technology elements that were introduced included a vibrating chisel plough (VCP), a land plane leveler (LP), a taipa (TP), which is an equipment that is utilized in the construction of relatively low levee bunds without deep depressions and pre–fertilization (PF) techniques. During the sowing phase, only certified seeds (CS) with a seed density (SD) of less than 150 kg/ha authorized by Colombian Agricultural Institute (ICA) were used, coupled with the usage of calibrated drill sowing (DS). Another element that is incorporated during the growth phase is water management, which refers to the implementation of a continuous irrigation system (CI) and a gravitational irrigation method for sloped fields, which is characterized by an intermittent application of water for several days from the top of the plot, in order to fill the end of the plot.

2.3 Methodology of analyzing pattern of AMTEC technology combinations (technology packages)

The K–means clustering algorithm was applied to analyze the combinations of the eight specified AMTEC technology elements adopted by farmers across Colombia. Combinations of the utilized technology elements VCP, LP, TP, PF, CS, DS, SD and CI were grouped into a few cohesive "clusters" and theoretically, 256 ($=2^8$) combinations can exist at most.

The K–means clustering algorithm clusters data by attempting to separate samples across N groups with equal variance and minimizes a criterion known as the inertia or within–cluster sum–of–squares. This algorithm requires the number of clusters to be specified. It scales well to a large number of samples and has numerous applications across various fields. The K–means algorithm divides a set of N samples X into K disjoint clusters C, with each described by the mean μ_j of the samples in the cluster. The means are commonly referred to as cluster *centroids*. Note that they are not, in general, points from X, although they live in the same space. The K–means clustering algorithm aims to choose centroids that minimize the inertia, or the within–cluster sum of squares criterion.

2.4 Methodology of determinants of the impact of the implemented AMTEC technology on paddy yield

To assess the impact of AMTEC technology adoption on yield that is an indicator of productivity in rice farming, we estimate a semi–log linear regression model by taking the average of all data points that belong to each cluster. The generic form of the semi–log linear regression model is very useful in the assessment of the impact of one or more dummy variables. The model framework is of the following form (Greene, 2012):

$$\begin{aligned} lny &= f(x_1, x_2 \ldots, x_k) + \varepsilon = x_1\beta_1 + x_2\beta_2 + x_3\beta_3 \\ &\quad + x_4\beta_4 + x_5\beta_5 + x_6\beta_6 + x_7\beta_7 + x_8\beta_8 + \varepsilon \\ &= \beta_1\, Vibrating\ Chisel\ plow\ (VCP) + \beta_2\, land\ plane\ leveler\ (LP) + \beta_3\, taipa\ (TP) + \beta_4\, pre\text{–}fertilization\ (PF) + \beta_5\, certified\ seed\ (CS) + \beta_6\, drill\ sowing\ (DS) + \beta_7\, seed\ density\ less\ than\ 150\tfrac{kg}{ha}\ (SD) \\ &\quad + \beta_8\, continuous\ irrigation (CI) + \varepsilon \end{aligned} \tag{1}$$

The dependent variable, y, is the yield in ton per ha in each cluster. In this study, the yield refers to the yield of raw green paddy rice. According to the 4th National Rice Census 2016 (FEDEARROZ, 2017), raw green paddy was cultivated in a field that is characterized by 20–26% humidity and 3–7% impurities.

The dependent variable in each case is expressed as a function of AMTEC technology elements, such that it represents a quantitative variable that denotes whether or not an RPU applies each AMTEC technology element. However, since the technology variable of interest is considered as an endogenous binary choice variable, the estimation may suffer from selection bias, in the sense that those farmers who achieve higher yields may have done so even without the adoption of technology owing to some unobserved factors, such as the quality of technology, the perceived environmental impact, etc. All independent variables VCP, LP, TP, PF, CS, DS, SD and CI are dummy variables. They are 1 (one) if a cluster applied and 0 otherwise. ε is an error term.

3 RESULTS AND DISCUSSION

3.1 Descriptive analyses

Table 2 depicts the characteristics of RPUs and whether or not specific AMTEC technology elements were adopted across both total RPUs and irrigated RPUs in Colombia. The average size of a Colombian RPU was 19.69 ha. Interestingly, 66.7% of the RPUs cultivated less than 10 ha. The average yield of a Colombian RPU was 5.508 ton/ha. Moreover, 59.3% of the RPUs received technical assistance for farm management. Furthermore, 34.1% of the RPUs hired agronomists as consultants and in addition, received technical assistance on supply distribution, rice milling and institutional assistance from organizations such as FEDEARROZ in addition to public sector institutes (to the tune of 14.3%, 3.8% and 7.1%, respectively). Only 10% of Colombian farmers availed of soil analysis. Moreover, most of their farms, which availed of soil analysis, were assessed less than 10 sampling points per one crop season. Farmers perceived that chemical analysis was more important than physical soil analysis because of the cost and duration.

Chisel plough implementation has only been applied by 4.6% of the farmers. Further, only 2.9% utilized VCP as an AMTEC technology element. Additionally, 40% of the farmers were categorized as un–mechanized farmers (small farmers) who utilize conventional tilling methods.

The result depicts that 10.5%, 16.5%, 3.9%, and 12.5% of the farmers applied tools such as land planes, levelers, laser levelers, sticks, and rails, respectively. This result accounted for the variations in the irrigation system of Colombia. We found that 24.8% and 13.5% of the farmers constructed levees (bunds) by utilizing a ribbing machine and TP, respectively. TP was applied in the contour–levee irrigation system that is a common land preparation and irrigation practice for rice cultivation in sloped fields across Colombia to facilitate efficiency in water usage (Takeda *et al.*, 2019). Another region used LPs to prepare small bunds (holding water) by making use of a ribbing machine as employed in lowland rice ecosystems across Asia and Peru. The irrigation system of Colombia was divided on the basis of three conditions including continuous (a gravitational irrigation system), pool (a lowland rice ecosystem), and rain water (a non–irrigated system). The results depict that 54.6% of the farmers implemented an irrigation sys-

Table 2. The characteristics of rice producing units (RPUs) and the adoption of AMTEC technologies in Colombia

Variables	**Unit**	Total RPUs (n=20174)		Irrigated RPUs (n=11007)	
		Mean	St. Dev.	Mean	St. Dev.
RPU's characteristics					
Average rice yield	ton / ha	5.508	1.818	6.64	1.385
Average RPU size	Hectare	19.692	62.717	13.337	38.052
< 1 ha	Dummy	0.061	0.24	0.075	0.263
1–< 2 ha	Dummy	0.137	0.344	0.13	0.336
2–< 5 ha	Dummy	0.261	0.439	0.281	0.449
5–< 10 ha	Dummy	0.208	0.406	0.25	0.433
10–< 20 ha	Dummy	0.132	0.339	0.136	0.342
20–< 50 ha	Dummy	0.116	0.321	0.086	0.28
50–< 100 ha	Dummy	0.046	0.208	0.026	0.16
100–< 200 ha	Dummy	0.025	0.156	0.011	0.104
200–< 500 ha	Dummy	0.01	0.1	0.005	0.069
500–< 1000 ha	Dummy	0.002	0.04	0.001	0.03
=> 1000 ha	Dummy	0.001	0.024	0	0.013
Receiving Technical Assistance	Dummy	0.593	0.491	0.729	0.445
Types of technical assistance					
Supply Distribution	Dummy	0.143	0.35	0.137	0.344
Particular*	Dummy	0.341	0.474	0.432	0.495
Rice Milling	Dummy	0.038	0.191	0.062	0.241
Institutional	Dummy	0.071	0.257	0.097	0.297
Soil Analysis	Dummy	0.100	0.300	0.097	0.296
Land preparation					
Chisel Plough Implementation	Dummy	0.046	0.208	0.048	0.214
Chisel plough types					
Vibrating (VCP)	Dummy	0.029	0.168	0.033	0.179
Rigid	Dummy	0.015	0.122	0.014	0.118
Leveling types					
Leveling Implementation	Dummy	0.364	0.481	0.574	0.495
Land plane (LP)	Dummy	0.105	0.307	0.301	0.368
Leveler	Dummy	0.165	0.371	0.071	0.459
Laser leveler	Dummy	0.039	0.193	0.11	0.257
Stick or rail	Dummy	0.125	0.331	0.162	0.313
Ban Implementation	Dummy	0.383	0.486	0.626	0.484
Ban types					
Taipa (TP)	Dummy	0.135	0.342	0.227	0.419
Ribbing machine	Dummy	0.248	0.432	0.399	0.49
Pre–fertilization (PF)	Dummy	0.136	0.343	0.145	0.352
Certified Seed (CS)	Dummy	0.449	0.497	0.613	0.487
Sowing types					
Drill sowing (DS)	Dummy	0.226	0.419	0.343	0.475
Transplant	Dummy	0.03	0.171	0.055	0.228
Manual	Dummy	0.328	0.47	0.534	0.499
Seeding					
<150 Kg/ha (SD)	Dummy	0.353	0.478	0.278	0.448
150 Kg/ha – <180 Kg/ha	Dummy	0.316	0.465	0.305	0.461
>180 Kg/ha	Dummy	0.331	0.471	0.416	0.493
Irrigation	Dummy	0.546	0.498	1.000	0.000
Continuous Irrigation (CI)	Dummy	0.312	0.463	0.571	0.495

Source: FEDEARROZ (2017); Note: Each AMTEC technology element is highlighted in grey; * Particular means farm owner contract and/or hired technical assistance directly.

tem in their own fields, such that 31.2% of the farmers implemented a CI system. According to Fedearroz, a CI system was regarded as one of the AMTEC technology elements that facilitates improved efficiency in water usage. The results also depict that 13.6% of the farmers applied PF techniques. In general, basal fertilizers such as Diammonium Phosphate (DAP), Chloride Potassium (KCl) etc. were applied during soil preparation, particularly by farmers who were implementing either a manual or a direct sowing method. In the case of transplanting, a pre–fertilizer was applied one or two days prior to transplanting. Pre–fertilizers included DAP, KCl, Sulfate Zinc (Zn), Sulfate Iron (Fe), Minor Nutrition, and Borax (B) (FEDEARROZ, 2014). FEDEARROZ recommended the undertaking of soil analysis prior to the application of PFs. However, in this study, it is difficult to identify whether farmers considered the results of soil analysis prior to applying PFs (FEDEARROZ, 2014).

A comparison of the total PRUs and irrigated RPUs reveal that the average size of an irrigated RPU is 32.3 % smaller and that 73.6 % of the farmers cultivate less than 10 ha. The average yield of an irrigated RPU was 6.640 ton/ha, such that it is 20% higher than total RPU average yield. The AMTEC technology elements of LP, TP, CS, DS and CI were more commonly adopted across irrigated RPUs (to the tune of 30.1%, 22.7%, 61.3%, 34.3% and 57.1 %, respectively). These results indicate that irrigated RPUs are more mechanized and are characterized by a greater degree of adoption of AMTEC technology.

3.2 Pattern of AMTEC technology combination under irrigated system

There were 162 technology clusters (or combinations) applied across 11,007 irrigated RPUs in Colombia. Such clusters can be summarized as follows: VCP was applied by 366 RPUs, LP was applied by 1,781 RPUs, TP was applied by 2,496 RPUs, PF was applied by 1,598 RPUs, CS applied was by 6,743 RPUs, DS applied by 3,774 RPUs, SDs that were less than 150 kg/ha were applied by 3,062 RPUs, and CI was applied by 6,287 RPUs.

Table 3 depicts the adoption patterns of AMTEC technology for twenty top–ranked clusters with the highest number of RPUs. The predominant technology combinations (technology packages) were adopted by 83.4% of the RPUs. The most commonly implemented technologies were CS, CI and DS (such that 75%, 75% and 60% of the top twenty clusters, adopted the specified technologies). These technologies are not expensive to adopt at the farm level. On the contrary, VCP was the least adopted by the top twenty clusters, since certain regions such as Llanos, Dry Caribbean, and Centro did not adopt tilling methods aimed at preventing soil erosion.

Table 4 presents the adoption pattern of AMTEC

Table 3. The adoption patterns of AMTEC technology elements for the top twenty clusters with the highest number of RPUs under an irrigated system

Clusters	VCP	LP	TP	PF	CS	DS	SD	CI	Number of AMTEC technology elements	Average Yield (ton/ha)	Number of RPUs
12	0	0	0	0	0	0	0	0	0	6.187	1704
0	0	0	0	0	1	0	0	0	1	6.562	1097
165	0	0	0	0	1	0	0	1	2	6.393	1056
168	0	0	0	0	0	0	0	1	1	6.220	1012
1	0	1	1	0	1	1	0	1	5	7.726	597
3	0	0	0	0	0	0	1	0	1	6.212	576
5	0	0	0	0	1	1	0	1	3	7.507	487
7	0	0	0	0	1	0	1	0	2	6.452	486
4	0	0	0	0	1	0	1	1	3	6.048	364
8	0	0	1	0	1	1	0	1	4	7.416	357
175	0	0	0	0	0	0	1	1	2	5.790	233
14	0	0	0	1	1	1	0	1	4	7.671	206
17	0	1	1	1	1	1	0	1	6	7.498	185
15	0	1	1	1	1	1	1	1	7	6.788	160
20	0	0	0	0	1	1	0	0	2	8.004	128
178	0	0	0	0	0	1	0	1	2	7.179	124
18	0	1	1	0	1	1	1	1	6	7.163	118
19	0	0	1	1	1	1	1	1	5	7.247	105
230	0	0	0	1	1	1	1	1	6	7.421	102
23	1	1	1	0	1	1	0	1	6	7.752	89
Number of clusters used an corresponding technology element	1	5	7	5	15	12	8	15			

Source: FEDEARROZ (2017); Number of RPUs = 11,007, Number of Clusters = 162

Table 4. The adoption patterns of AMTEC technology elements for the top twenty clusters with the highest average yield under an irrigated system

Clusters	VCP	LP	TP	PF	CS	DS	SD	CI	Number of AMTEC technology elements	Average Yield (ton/ha)	Number of RPUs
41	1	0	1	1	1	1	0	1	6	9.514	22
152	1	1	0	0	1	0	1	0	4	9.375	1
136	1	0	0	1	1	1	0	1	5	9.000	2
144	1	0	0	0	1	1	0	1	4	8.750	1
153	1	0	0	1	1	1	1	0	5	8.750	1
92	1	1	1	0	1	1	1	1	7	8.469	4
160	1	0	0	1	1	0	1	1	5	8.458	1
114	0	1	0	1	1	0	0	1	4	8.438	3
131	0	0	1	1	0	1	0	0	3	8.313	2
156	1	0	1	0	1	0	1	1	5	8.300	1
177	0	1	0	1	1	1	0	0	4	8.212	14
87	1	1	0	1	1	1	1	1	7	8.145	6
49	1	0	1	0	1	1	0	1	5	8.131	20
157	0	0	1	1	1	0	0	0	3	8.125	1
70	1	0	0	1	1	1	1	1	6	8.113	14
137	1	0	0	1	1	0	1	0	4	8.091	1
26	1	0	1	1	1	1	1	1	7	8.049	69
20	0	0	0	0	1	1	0	0	2	8.004	128
116	1	1	1	0	1	1	1	0	6	8.000	2
123	0	0	1	0	1	1	1	0	4	7.972	2
Number of clusters used an corresponding technology element	**14**	**6**	**9**	**12**	**19**	**14**	**11**	**11**			

Source: FEDEARROZ (2017); Number of RPUs = 11,007, Number of Clusters = 162

technology for the twenty top–ranked clusters with the highest average yield. 295 of the RPUs achieved an average yield of more than 8.410 ton/ha. CS, VCP, DS and PF were the most commonly adopted AMTEC technology elements (such that 95%, 70%, 70% and 60% of the top twenty clusters, adopted the specified technologies). On an average, each cluster from among the top 20 clusters adopted between four and five common AMTEC technologies. LP and TP were the least adopted by the top 20 clusters. In fact, the vast majority of the technology combinations (technology packages) tended to exclude these technology elements. Six clusters that comprised of more than ten RPUs were clusters 41, 177, 49, 70, 26, and 20, wherein the majority applied the technology elements CS, VCP, DS and PF.

3.3 Determinants of the impact of the implemented AMTEC technology on paddy yield

The result of regression model to identify the impact of the implementation of AMTEC technologies on yield was depicted in Table 5.

The value of R–*squared* indicated that 40.7% of the variation in the yield can be explained by statistically significant independent variables. *Tetrachoric* correlation (Edwards and Edwards, 1984) was applied prior to the application of regression analysis, and we found that there is no significant correlation between the independent variables.

The coefficients of the LP and TP variables were negative and significantly different. This suggests that with all other things held constant, the yields of RPUs that apply these technologies were less than those that did not adopt these AMTEC technologies. Because the quality of field leveling by LP and bund construction by TP widely affected by farmers machine operation skills and their prior experiences in using these technologies. Also, because of difficulty in acquiring these technologies to improve the yield, the results indicated that the majority of farmers were unable to effectively implement LP and TP technologies. To adopt these technologies more effectively, the AMTEC program should transfer these in simpler and uniform ways.

On the contrary, the degree of adoption of DS and CS technologies implied that the RPUs, which adopted these technologies, would achieve a higher average rice yield in comparison to RPUs, which did not adopt these technologies, keeping other variables constant. These results indicate that DS and CS technologies were easy to adopt for the purpose of facilitating an increase in rice productivity under the irrigation system in Colombia.

Interestingly, the CI coefficient contributed negatively (not significantly) to the yield, since under the conditions of irrigation, in addition to implementing a CI system, a pool irrigation system was found to effectively facilitate a higher yield with a sufficient water supply during the crop season. This result suggested that the

Table 5. The impact of the implementation of AMTEC technology elements on rice yield under an irrigated system

Variable	Coef.	Std. Err.	t		95% Conf.	
Vibrating Chisel plow (VCP) (= 1)	–0.010	0.029	–0.350		–0.068	0.047
Land Plane leveler (LP) (=1)	–0.121	0.026	–4.610	***	–0.173	–0.069
Taipa (TP) (=1)	–0.057	0.026	–2.180	**	–0.109	–0.005
Pre-fertilization (PF) (=1)	–0.024	0.027	–0.880		–0.076	0.029
Certified Seed (CS) (=1)	0.209	0.027	7.640	***	0.155	0.263
Drill Sowing (DS) (=1)	0.118	0.027	4.440	***	0.065	0.170
Seed density less than 150 kg/ha (SD) (=1)	–0.030	0.026	–1.140		–0.081	0.022
Continuous Irrigation (CI) (=1)	–0.040	0.026	–1.510		–0.091	0.012
Constant	8.716	0.035	246.830	***	8.647	8.786

Source: FEDEARROZ (2017); n = 162 AMTEC technology clusters applied across 11,067 irrigated RPUs, F= 13.153***, R–squared= 0.407; **, *** are significant different at 5% and 1% level, respectively

implementation of a transplanting method, coupled with the establishment of a pool irrigation system that is similar to that of Asian rice farms will positively impact Colombian rice cultivation in the future.

In Colombia, with five different rice crop regions, highly diverse rice cultivation technologies and environmental conditions, it is critical to consider the best combinations of AMTEC technology elements and adopt technologies that are suitable to specific regions and to the rice ecosystem as a whole, to facilitate improved productivity and a reduction in the total production costs in the future.

4 CONCLUDING REMARKS

This study determines the number of the combinations of the eight specified AMTEC technology elements adopted by farmers and their patterns as well as investigates the impact of the implementation of AMTEC technological combinations through the utilization of cross sectional data collected from The 4th National Rice Census 2016 (FEDEARROZ, 2017). K–means clusters are used to identify the technology bundles of irrigated RPUs. A regression model was employed to assess the impact of AMTEC technology in the achievement of higher paddy yields.

The average yield of the top twenty clusters with the highest yields under an irrigated system was 8.410 ton/ha, wherein each cluster adopted a combination of the eight technology elements. The average number of implemented AMTEC technologies for the top twenty clusters with the highest yield were 4.8. Land preparation tools (VCP and TP), CS, and DS were the most commonly adopted technologies by those farmers who achieved the highest yields. On the contrary, technology elements such as LP and TP were the least adopted. The result also highlighted the positive impact of the adoption of DS and CS on paddy yield outcomes. Overall, it is still necessary to scientifically confirm the relations and interactions between each technology element for the future transfer of technology under the AMTEC program. The research approach adopted in this study is novel, as there was a dearth in the number of studies that identified and assessed the impact of the adoption of multiple technologies on rice production.

Indeed, a limitation of the regression model applied here is that the absence of other unobserved socioeconomic characteristics that may contribute to the impact of technology and which may influence the quality of each technology element is not considered. Nevertheless, the variable that denotes the impact of adopted AMTEC technology would be more reliable. A policy implication arising from the findings of this study is that the efforts involved in the implementation of AMTEC technologies should be in keeping with the geographical conditions and a farmer's situation and experiences. This may increase the probability of the continuity and acquisition of relevant technical knowledge. Further analysis maybe required in future across rice cultivation regions and various irrigation systems. Furthermore, the implementation of technology may generate a higher employment rate and may hence, facilitate the steady growth of local agricultural communities, and may enable in–country refugees to return to their villages. The adoption of these AMTEC technology elements with agro climatic services and precision agriculture as planned in the AMTEC 2.0 program, would contribute to food security on a global scale.

AUTHOR CONTRIBUTIONS

All listed authors have contributed in this manuscript. Widya Alwarritzi carried out the detail study's design, statistical analysis and drafted the manuscript. Teruaki Nanseki build up the research flame and carried out the basic study' design as well as advised the interpretation of statistical analysis and edited the manuscript. Satoshi Ogawa supplied data source, advised the interpretation of statistical analysis and edited the manuscript. Nguyen Thi Ly reanalyzed data and edited the manuscript. Yosuke Chomei assisted the study' design, advised the data interpretation and edited the manuscript. Nilson Alfonso Ibarra Becerra, Ricardo Andres Sanchez Galvis, Myriam Patricia Guzmán García, and Jose Levis Baron Valbuena supplied data source, advised the data interpretation and edited the manuscript. All

authors have read and approved the final manuscript hat builds on the manuscript of **"The adoption of the Latin American rice production system through the implementation of advanced field management practices: An evaluation of technology adoption patterns and the impact on yield in Colombia"**.

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