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Contract Farming, Farm Mechanization, and Agricultural Intensification: The Case of Rice Farming in Cote d'Ivoire[*]

Yukichi Y. Mano[†], Kazushi Takahashi[‡], and Keijiro Otsuka[§]

Abstract

It is critically important to intensify farming systems by disseminating proper agronomic practices and promoting the increased application of inputs to raise agricultural productivity in sub-Saharan Africa. However, the region's public agricultural extension systems are weak, and their input and output markets often fail to function properly. Under these circumstances, contract farming (CF) is expected to be a promising way to overcome market imperfections by providing inputs, production training, and marketing services. We examine this possibility by analyzing the case of rice production CF in Cote d'Ivoire. We find that CF did not lead to farming intensification, due mainly to the inadequate and uncertain provision of tractor services. Further analysis reveals a complementarity between tractor use and labor inputs, whereby tractor use in land preparation enhanced the adoption of input- and labor-intensive practices in subsequent farming activities, thereby increasing labor use and improving land productivity. The diffusion of tractors is thus likely to be key to the intensification of rice farming systems in sub-Saharan Africa.

Keywords: contract farming, rice production, tractor, farm mechanization, agricultural intensification, Green Revolution, sub-Saharan Africa, Cote d'Ivoire

JEL classification: N57, O12, O13, Q12, Q16, Q18

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1. Introduction

The intensification of land use is critical for food security and poverty alleviation in many countries in sub-Saharan Africa (SSA), where arable land per capita has been rapidly decreasing due to rapid population growth (Holden and Otsuka 2014; World Bank 2007). Among major cereal crops, rice has the most promising prospects of boosting crop yields in SSA because improved seed-fertilizer technologies and agronomic practices—such as levelling, bund construction, and transplanting in rows—are well-established and transferable from Asia (Otsuka and Larson 2013, 2016).

However, the adoption of the recommended technology has been disappointingly low across many countries in SSA. The literature reveals failures in input markets, credit markets, and product markets, as well as a lack of institutions able to disseminate technological information as major constraints on the adoption of improved practices in SSA in general (e.g. Barrett et al. 2017; Croppenstedt et al. 2003; Duflo et al. 2011; Ndjeunga and Bantilan 2005) and on the intensification of rice farming in particular (e.g., Kijima et al. 2012; Saliu et al. 2016; Njeru et al. 2016; Otsuka and Larson 2016). Given the underdevelopment of public extension services, which were weakened in SSA by structural adjustment policies in the 1980s and 1990s, private companies are expected to fill that gap through such means as contract farming (CF). However, CF is generally adopted for such high-quality products as fresh vegetables and fruits, and livestock products (Barrett et al. 2012; Otsuka et al. 2016; Oya 2012), and we know little about whether CF is effective in enhancing the productivity of staple crops such as rice.

To fill this research gap, this study (1) examines whether CF helps enhance rice productivity and profits through the adoption of improved agronomic practices, and (2) investigates the detailed mechanisms by which CF achieves or fails to achieve high profitability. We draw on a case in Cote d'Ivoire, where CF for rice farming was recently introduced to increase domestic rice production. In Cote d'Ivoire, unlike other SSA countries, improved seed-fertilizer technologies have been widely diffused due to training provided by local governmental and international organizations such as AfricaRice (formerly known as "WARDA" [West Africa Rice Development Association]). In fact, virtually all the rice-growing farmers we study apply modern varieties of rice and significant amounts of chemical fertilizer.

On the other hand, Cote d'Ivoire's difficulties are similar to those of other SSA regions, in that proper land preparation is difficult due to the absence of draft animals, and the tractor rental market is underdeveloped (Binswanger 1978, 1986; Binswanger and Pingali 1988; Pingali 2007; Takeshima et al. 2013; Takeshima 2015; Takeshima et al. 2015).[1] Manual land preparation is possible but laborious without sufficient irrigation facilities, which could provide a soft soil mass. Because of constraints on ploughing by animals and tractors, expanding the cultivation area is difficult, as is the intensification of land use through improved agronomic practices such as levelling, bund construction, and transplanting.[2] Contract farming is expected to provide tractors in a timely manner.

Our main findings are as follows. Contrary to our expectation, CF was not effective in enhancing rice farming productivity at our study site, partly because the site's rice yield was already reasonably high and more importantly because CF failed to provide tractors in a timely manner since the contractor, a private agricultural company, lacked experience in rice production and was unable to coordinate tractor use across villages. This failure induced contracted farmers to adopt fewer of the recommended agronomic practices, such as seed incubation and transplanting, leading to decreased labor input per hectare per season. In other words, CF farmers reduced labor input, not because of better access to tractors, but because of an unavailability or uncertain availability of tractors. Our further investigation reveals that the use

[1] Note that "tractor" refers to a power tiller for our study site.

[2] Farming intensification may be constrained by different factors in different environments. Emerick et al. (2016) recently documented that improved technology in rice variety (i.e. flood tolerance) reduced production risk, promoted the intensive application of input, increased the adoption of agronomic practices, and improved agricultural productivity in eastern India.

of tractors led to the adoption of input- and labor-intensive farming practices and to improved productivity and profitability of rice farming overall.

Our study contributes to two strands of the literature. First, we address the role of CF in rice production in SSA, which is underexplored in the literature. To the best of our knowledge, only two studies show that CF has improved the yield and incomes of rice-growing farmers in SSA, including in Tanzania (Nakano et al. 2014) and Benin (Maertens and Velde 2017). However, unlike ours, these studies do not examine the underlying mechanism in detail, including the potentially complementary roles of machinery and the adoption of improved agronomic practices. To obtain deeper insights, we not only compare CF farmers with non-CF farmers in their use of tractors and other inputs, but we also compare non-CF farmers who use tractors with non-CF farmers who prepare their land manually in their adoption of input- and labor-intensive farming practices.[3]

Second, this study sheds new light on the question of whether tractor use is saves labor, or is more labor-intensive. As exemplified by the induced innovation theory, the dominant view is that a new technology is employed to save a factor of production, the relative price of which increases. For example, Boserup (1965) argues that the population pressure on land induces the adoption of labor-intensive farming systems to serve as a substitute for increasingly scarce factors of production, such as land. Similarly, Hayami and Ruttan (1985) argue that population pressure induces the development and adoption of land-saving and yield-enhancing biological and chemical technology, whereas the mechanization and adoption of labor-saving technologies are induced when wages increase. The substitution of capital for labor and draft animals has been widely observed in regions where wages are rising in the US since the 1940s, in Europe and Japan since the 1950s, and in tropical Asia since the 1960s. As the conventional view suggests, tractor use should replace labor in land preparation in the SSA. However, a unique feature of

[3] In the latter comparison, we focus on non-CF famers to identify the effect of tractor use alone.

SSA is that thoroughly ploughed land increases the profitability of input- and labor-intensive agronomic practices, so that the total application of labor and fertilizer per unit of land increases with the use of tractors. This finding is consistent with the emerging literature that suggests the mechanization may potentially enable input-intensive production in SSA (Takeshima et al. 2013) and implies that promoting agricultural mechanization does not necessarily lead to increased rural unemployment (Pingali 2007).

The rest of this paper is organized as follows. Section 2 explains the study setting and presents empirical hypotheses on the effectiveness of CF in the provision of tractors and other inputs. Section 3 explains the study's empirical strategy, and Section 4 discusses the estimation results on the impacts of CF. After the hypotheses regarding the effects of tractor use are proposed in Section 5, Section 6 examines the descriptive statistics of tractor use in our study site. Section 7 then discusses the estimation results on the effect of mechanization on the intensification of rice farming. Finally, Section 8 concludes the paper.

2. Study Setting

2.1 CF in Cote d'Ivoire

Our study site is the Yamoussoukro district, where the capital city is located. It is connected to the highway stretching from the country's business center, Abidjan (about two hours away), thus providing good market access. The local government and a foreign firm jointly established an agricultural company to conduct CF in rice farming so as to enhance rice farming productivity in the region.[4] According to our interviews with local farmers, however, this agricultural company was neither familiar with the local production environment nor well-organized in CF management, although it employed several agronomists.

[4] The government of Cote d'Ivoire divided the country into eight regions based on vegetation and gave permission to a large foreign or joint agricultural trading company to operate exclusively in each region.

This agricultural company started CF by contracting with three farmers in March 2013 as a pilot phase to produce certified seeds. This was followed by another pilot phase in October 2013, involving seed and paddy production with 55 farmers in four villages. The scheme gradually expanded and by July 2014 involved eight villages. Adjao (2016) explains that this scheme was intended (at least initially) to be developed over five years with five main objectives: (1) the creation of a model farm for promoting appropriate mechanization and incorporating a modern seed center; (2) the rehabilitation of existing rice schemes; (3) the development of additional arable irrigated land; (4) the establishment of a complete rice processing unit; and (5) the creation of storage capacity.

The contract determined the responsibility of each party involved. According to the original contract signed by typical CF farmers, the major terms covered the provision of inputs, technical services, and marketing services by the agricultural company. Specifically, the company was to secure tractors for land preparation and provide improved seeds, fertilizers, and other chemical inputs on credit, and training in agronomic practices. The farmers were to undertake production under the supervision of the company. The agricultural calendar and the choices and prices of inputs were to be subject to negotiation between the company and the farmers' cooperative. The company was to harvest rice crops and the paddy was to be purchased at a predetermined price for the 2014/2015 season.

Thus, the contractor would provide inputs (including tractors) on credit as well as technical services, and the farmers would adopt appropriate agronomic practices and deliver the output to the contractor. This is a typical form of CF, with the possible exception of the provision of tractor services.

2.2 Hypotheses

Given that CF is designed to overcome the failures in the input and output markets and in the provision of technical services (Otsuka et al. 2016; Maertens and Velde 2017; Key and Runstein 1999; Grosh 1994), we postulate the following:

Hypothesis CF1: Contract farming increases the use of inputs, including the use of tractor services.

Hypothesis CF2: Contract farming increases the adoption of improved agronomic practices.

By increasing the application of improved inputs and the adoption of improved technologies, CF is expected to help farmers improve the output quality, production efficiency, and profitability in rice farming. Thus, we propose the following:

Hypothesis CF3: Contract farming leads to the production of higher-quality rice, which will be reflected in higher rice prices.

Hypothesis CF4: Contract farming leads to improved rice farming performance, which may be reflected in higher rice yields, rice income, and rice production profits per hectare of land.

Note that we assume that variations in paddy price in the same cropping season reflect differences in rice quality. We test our hypotheses by analyzing the unique case of CF rice farming in Cote d'Ivoire using our primary household data.

2.3 Data

We conducted a household survey in early 2015 on the sample rice farmers in 10 villages near Yamoussoukro. The data cover the rice plots of farmers who cultivated in the 2014 and 2015 crop seasons. At our study sites, CF started full operation in July 2014, and our sample distinguishes between the pre- and post-July 2014 periods. For convenience, we call the period before July 2014 the "pre-treatment period" and the period after the "post-treatment period." We interviewed the CF farmers using the list provided by the agricultural company. The sample farmers cultivated rice at least once during the year.[5] Our sample CF farmers cultivated 68 plots in the pre-treatment period, whereas they cultivated only 33 plots in the post-treatment period. According to our field interviews with these farmers, the agricultural company failed to provide the tractors in a timely manner. As a result, some farmers could not fully implement the improved management practices, while others gave up rice cultivation during that season. The non-CF farmers were randomly selected from the same villages. These farmers cultivated 104 plots in both the pre-treatment and post-treatment periods.

2.4 Descriptive analysis

Table 1 presents the basic characteristics of the sample farmers who cultivated rice in the pre-treatment and post-treatment periods by CF status. We conducted a *t*-test of the equality of means between each column and the third column (i.e. the non-CF farmers who cultivated rice in the pre-treatment period are the reference group). The average household head was a male in his mid-40s with barely any education. The average household size was nine members, and the households had learned six improved agronomic practices via agricultural training programs.[6] They cultivated 0.75 hectare or more in the pre-treatment period, but the average size of the

[5] We have 220 sample farmers, 147 of whom cultivated one plot in one cycle only.

[6] The institutions that provided this training were either governmental organizations, such as L'Office National de Développement de la Riziculture (ONDR; National Office of Rice Agriculture Development) and Agence National D'appui au Development Rural (ANADER; National Agency to Support Rural Development), or international organizations such as AfricaRice (formerly known as 'WARDA' [West Africa Rice Development Association]), the World Bank, and the governments of Japan and EU nations.

cultivated plots slightly decreased in the post-treatment period. The reduction of cultivated land is especially apparent among the CF farmers in the post-treatment period.

According to the sample farmers and key informants in the region, the CF farmers were highly dependent on the agricultural company to secure tractors as promised in the contract, but, to their surprise, the company often failed to supply tractors in a timely manner due to their lack of experience in rice production and their failure to coordinate tractor use across villages. Furthermore, the supply of tractors was limited and was dominated by Chinese products. These tractors broke down easily and lacked spare parts or a maintenance system for repairs. Since rice is typically more widely cultivated in the latter half of the year, the demand for tractors surged against their limited supply in the post-treatment period, making it difficult to secure tractors during this period. This increasing cost of securing tractors may explain the smaller size of rice cultivation and the substantially reduced number of cultivated plots in the post-treatment period.

Table 2 illustrates the adoption of agronomic practices and the amount of applied chemical fertilizer on the rice plots cultivated by the CF and non-CF farmers. We pay special attention to the agronomic practices commonly adopted in rice production in Asia, which led to success during the rice Green Revolution (David and Otsuka 1994; Otsuka and Larson 2016). These agronomic practices, known to be highly complementary with each other, are levelling, bund construction, canal construction, seed selection, seed incubation using paper or straw, transplanting, and transplanting in rows. For example, proper land preparation and bund construction are prerequisites for better water and weed control and more effective transplanting, while seed incubation is associated with the use of nurseries and transplanting, which in turn improves weed control. From the pre- to the post-treatment period, the number of adopted agronomic practices declined from 4.7 to 3.7 on the CF plots and from 4.7 to 4.4 on the non-CF plots. The last column provides an unconditional difference-in-differences (DID) regression estimate of the CF effect (i.e. the difference in the time trend of the number of agronomic practices adopted on the CF and non-CF plots). We find that the CF is negatively and significantly associated with the number of improved practices adopted. As mentioned, it was difficult for CF farmers to secure tractors in a timely manner in the post-treatment period, and they seem to have been discouraged from adopting improved agronomic practices, particularly seed incubation and transplanting in rows, despite their initial plan to disseminate them.

On average, the sample farmers applied about 250 kilograms of chemical fertilizer per hectare.[7] This highly intensive application of chemical fertilizer in Cote d'Ivoire is likely to be related to the technical training and campaigns provided by the government through ONDR and ANADER and by AfricaRice, as well as the well-functioning chemical fertilizer market. However, when tractors were unavailable and land preparation was poor, the farmers seem to have reduced their application of chemical fertilizer, though the effect was not statistically significant.

We next examine the cultivated land size and the application of labor and machinery, which consisted mainly of tractors for land preparation (see Table 3). For both groups, the cultivated land size and the application of labor and machinery were smaller during the post-treatment period, which may be related to the reduced availability of tractors. The DID-estimates of the CF effects on the application of family labor and machine costs were significantly negative. This is also consistent with the fact that the agricultural company failed to secure tractors. In fact, the CF effect on the application of family labor is negative for all the farming tasks; in particular, the estimated effect is significantly negative for land preparation (see Table 4). The cost of hired labor also declined in the post-treatment period for various farming tasks, but the unconditional DID-estimate of the CF effect was not statistically significant (see Table 5). We also observe reductions in the cost of machinery use in land

[7] Njeru, Mano, and Otsuka (2016) summarize the FAO data that farmers in Indonesia and Kenya apply almost 150 kilograms of chemical fertilizer per hectare, and much lower amounts in other countries in southeast and south Asia and in Sub-Saharan Africa.

preparation and other tasks, and the effect of CF on these is also negative and significant (see Table 6).

We now turn to the performance of rice farming (see Table 7). We observe that the average paddy price received by the non-CF farmers declined from 186 FCFA in the pre-treatment period to 173 FCFA in the post-treatment period, which coincided with the main rice farming season. Thus, the market supply of paddy was generally high. By contrast, the paddy price remained at almost the same level among the CF farmers (i.e. 182 FCFA in the pre-treatment period and 184 FCFA in the post-treatment period). The DID estimate of the CF effect on the paddy price was 14.33 FCFA, but it was not statistically significant.

The reduced application of labor and machinery in agronomic practices was not necessarily associated with a reduction in rice yield.[8] Somewhat surprisingly, it was associated with increased income and profits from rice farming, where income is sales revenue minus the paid-out cost, and profit is income minus the imputed cost of family labor.[9] This occurred presumably because the climatic conditions are more favourable to rice farming in the main rice season—the latter half of the year, or the post-treatment period in our study. Thus, farming performance was better in the post-treatment period except for the paddy price, whereas we observed little systematic difference in rice production performance between the CF famers and non-CF farmers. In fact, none of the unconditional DID-estimates of the CF effects on agricultural performance was statistically significant (see Column 5 of Table 7).

[8] Notice that rice yield is as high as 4 tons per hectare (Table 7). This exceeds the average yield of 2.4 tons per hectare in SSA, and is comparable to the average yield in irrigated areas in SSA and tropical Asia (Njeru, Mano and Otsuka, 2016).

[9] Note that we compute profit without deducting the labor cost of bird-scaring because this activity is often carried out by children at play, whose market wage is not available.

3. Empirical Strategy

The descriptive analysis shows that the average areas of the rice plots cultivated by the CF and non-CF farmers were similar. Both reduced the application of labor and capital in the post-treatment period, when the availability of tractors declined. Although the descriptive analysis is informative, we attempt to control for the covariates affecting participation in CF, the application of inputs, the adoption of agronomic practices, and rice farming performance in order to accurately evaluate the effect of CF.

3.1 Doubly robust estimator

We apply a doubly robust (DR) estimator to evaluate the effectiveness of CF in rice farming. The DR method is more effective than the propensity score matching estimator and the inverse probability weighting (IPW) estimator because it can provide a consistent estimate of the average treatment effect (ATE), as long as either the propensity score $p(X)$ (i.e. the probability model of participating in CF as a function of the farmers' characteristics) or the regression function of outcomes Y in terms of covariates X is correctly specified (Wooldridge 2010). Moreover, the asymptotic variance in the DR method is smaller than that in the IPW estimator. Specifically, the expected outcome under the treatment $\mathrm{E}(Y_1)$ by the DR method is expressed as

$$\widehat{E(Y_1)} = \frac{1}{N}\sum_{i=1}^{N}\left[\frac{C_i}{p(X_i)}Y_{1i} + \left(1 - \frac{C_i}{p(X_i)}\right)\widehat{Y_{1i}}\right] ,$$

where variable C_i indicates the treatment status of plot i, and $\widehat{Y_{1i}}$ is the predicted value from the regression function of the outcome variable in terms of covariates. If the propensity score $\mathrm{E}\left(\frac{C}{p(X)}\right)$=1, and the regression specification are correct, then $\mathrm{E}\left(\widehat{Y_1}|X\right) = \mathrm{E}(Y_1|X)$. Thus, if either one is true, we can estimate $\mathrm{E}(Y_1)$ without bias. Similarly, we can also estimate the expected outcome under the control $\mathrm{E}(Y_0)$ by calculating

$$\widehat{E(Y_0)} = \frac{1}{N}\sum_{i=1}^{N}\left[\frac{1-C_i}{1-p(X_i)}Y_{0i} + \left(1 - \frac{1-C_i}{1-p(X_i)}\right)\widehat{Y_{0\iota}}\right] .$$

Taking the difference between the two estimators above, $E(\widehat{Y_1 - Y_0}) = \widehat{E(Y_1)} - \widehat{E(Y_0)}$, we can obtain an unbiased estimate of ATE.[10] We explain each component of the DR method, the propensity score, and the regression function of the outcome below.

3.2 Participation in contract farming

We apply the DR method to the case of multiple treatment statuses. As part of the DR method, we run the multinomial probit model of CF to estimate the propensity score:

$$\mathrm{Prob}[\mathrm{C}_i = k|X_i] \qquad ,$$

where C_i is a variable taking value k if plot i is under treatment k. Specifically, (1) k = 1 presents the plot cultivated by the CF farmer in the pre-treatment period; (2) k = 2 presents the plot cultivated by the CF farmer in the post-treatment period; and (3) k = 3 presents the plot cultivated by the non-CF farmer in the post-treatment period. The reference group is the plot cultivated by the non-CF farmer in the pre-treatment period. Covariate X_i is the vector of the basic characteristics of plot i and the farmer who cultivates it. The basic characteristics X_i consist of (1) the number of improved agronomic practices that the farmer has learned in formal agricultural training programs; (2) the age of the household head and its square term; (3) a dummy variable for the household head who completed primary school or above; (4) the number of household members; and (5) the logarithmic value of agricultural assets.

[10] We used the STATA command **teffects ipwra** to implement the DR method.

3.3 Agronomic practices and farming performance

The remaining part of our DR estimation assesses the effectiveness of CF on outcomes of interest, including the adoption of agronomic practices, the application of inputs, and rice farming productivity and profitability, by estimating the following regression function:

$$\mathrm{Y}_i = \alpha + \gamma C_i + X_i^{\prime} \beta + \varepsilon_i,$$

where Y_i is the outcome variable related to the adoption of improved agronomic practices, the application of inputs, paddy prices, and productivity and profitability in rice farming; X_i is the vector of the basic characteristics of plot i and the farmer who cultivated it; α, γ, and β are the regression parameters to be estimated; and ε_i is the random error term.

Outcome variable Y_i is represented by (A) the adoption of agronomic practices, consisting of (A1) the number of adopted improved agronomic practices; (A2) a dummy variable for levelling; (A3) a dummy variable for bund construction; (A4) a dummy variable for canal construction; (A5) a dummy variable for seed selection; (A6) a dummy variable for seed incubation using paper or straw; (A7) a dummy variable for transplanting; (A8) a dummy variable for transplanting in rows; (A9) the applied amount of chemical fertilizer in kilograms per hectare; (B) the application of major production factors, consisting of (B1) the cultivated land size; (B2) the application of family labor measured in person-days per hectare; (B3) the cost of hired labor per hectare; (B4) the cost of machinery per hectare; and (C) rice farming performance, consisting of (C1) the price of paddy; (C2) rice yield; (C3) income from rice farming; and (C4) profit from rice farming.

4. Estimation Results on the Effects of CF

Table 8 presents the DR estimation results regarding the adoption of improved agronomic practices with the plots of non-CF farmers in the pre-treatment period used as a control group.

The last three rows in the table present the estimated CF effect, its chi-square statistic for the significance test, and the associated *p*-value. We find that both the CF and non-CF farmers adopted fewer improved agronomic practices in the post-treatment period and that the estimated CF effect was not statistically significant. Examining the adoption of each practice in turn, we find that the CF effect was significantly positive on the adoption of levelling, whereas the CF effect was significantly negative on the adoption of seed incubation using paper or straw, transplanting, and transplanting in rows. The CF effect on the amount of applied chemical fertilizer was negative but not statistically significant. Overall, there is no indication that the CF systematically increased the adoption of improved agronomic practices or the application of chemical fertilizer, which contradicts hypotheses CF1 and CF2. As discussed above, the farmers in our study site had many opportunities to obtain formal training in improved agronomic practices and had good access to the major input and output market, Abidjan, which is only two hours away. These favourable conditions may explain why the non-CF farmers adopted the improved agronomic practices and applied chemical fertilizer to almost the same extent as the CF farmers did.

Table 9 presents the estimated effects of CF on cultivated land size, the application of family labor measured in person-days per hectare, the cost of hired labor, and the cost of machinery. Both the CF and non-CF farmers in the post-treatment period cultivated a smaller land size and applied significantly less family and hired labor and machinery than the non-CF farmers did in the pre-treatment period. However, the cultivated land size, the application of family labor, and the costs of hired labor and machinery were much more reduced for the CF farmers. As a result, the estimated CF effect on the application of labor and machinery was significantly negative, indicating again that hypothesis CF1 is invalid.

Table 10 shows the estimated effects of CF on paddy price, yield, and income and profit from rice farming. Income increased by 20% to 30% and profit by 40% to 50% among both the CF and non-CF farmers in the post-treatment period. This may be related to the fact that the post-treatment period coincided with the favourable rice cultivation season. Overall, the estimated CF effect was insignificant for the paddy price, income, and profit, while the CF effect was significantly negative for the rice yield. These results are inconsistent with hypotheses CF3 and CF4.

Overall, CF did not systematically improve input application, including the use of tractors, the adoption of improved agronomic practices, or rice farming performance. The failure to improve rice profitability through CF is in sharp contrast to the findings of studies conducted in Tanzania (Nakano et al. 2014) and Benin (Maertens and Velde 2017), and is thus worth examining in more detail. We suspect that the unreliable availability of tractors is one of the key reasons for this result, while another likely reason would be the fact that yield is already high (see the discussion in footnote 8).

5. Impact of Mechanization

The conventional view of agricultural development assumes that capital substitutes for labor as wages increase due to, for example, the development of the non-farm sector (e.g. Hayami and Ruttan 1985). However, our analysis of CF in Cote d'Ivoire suggests that the unreliable availability of tractors reduced the application of total labor use and the adoption of improved agronomic practices, suggesting the potentially complementary roles of capital and labor, which is discussed in Takeshima et al. (2013) and Pingali (2007). To identify the mechanisms behind the failure of CF observed in our case, we explore in this section whether significant complementarity exists between capital and labor in the intensification of rice farming. In particular, we explore the importance of tractor use in land preparation, which provides a basis for the application of labor-intensive agronomic practices. Based on these considerations, we postulate the following:

Hypothesis M1: Tractor use leads to the intensive use of paddy land for rice cultivation.

Hypothesis M2: Tractor use leads to the adoption of improved agronomic practices (e.g. the implementation of levelling and bund construction, a greater application of fertilizer, a more frequent adoption of transplanting and hand weeding, and a greater application of labor inputs).

Hypothesis M3: Tractor use leads to improved rice farming performance, which may be reflected in higher rice prices and in higher rice yields, rice incomes, and rice production profits per hectare of land.

6. Descriptive Statistics on Mechanization

We analyze the effects of mechanization without the impact of CF by using the sample of non-CF farmers. Table 11 compares the basic characteristics of the farmers and rice plots between the plots the farmers cultivated using tractors (the "tractor plots") and the plots the farmers cultivated manually (the "manual plots"). The two groups had similar basic characteristics, except that the farmers who used tractors had larger families, cultivated more often in the pre-treatment period, and had better water access.

Table 12 compares the adoption of improved agronomic practices and the application of chemical fertilizer by the use of tractors. The number of adopted agronomic practices was significantly greater on the tractor plots. In particular, the use of tractors led to a higher adoption of levelling, bund construction, canal construction, and seed incubation, but a lower adoption of seed selection. The farmers also applied significantly more chemical fertilizer on the tractor plots, which are more thoroughly ploughed.

Table 13 presents the cultivated land size, the application of family labor, and the costs of hired labor and machinery with the use of tractors. While there was no significant difference in the application of family labor, the tractor plots were larger, and the farmers applied significantly more hired labor and machinery. To analyze the application of labor in more detail, Tables 14 and 15 present the application of family and hired labor, respectively, across different tasks. Tractor use does not seem to affect the application of family labor across different tasks, whereas the farmers applied significantly more hired labor for crop establishment, crop care, and harvesting on the tractor plots. There is a weak indication that tractor use saved labor for land preparation, but, more importantly, it also induced an intensification of the farming system and increased the application of labor, which more than offset the reduction in labor use for land preparation.

Table 16 presents the paddy price, rice yield, and income and profits from rice farming through the use of tractors. Paddy price, rice yield, rice income per plot, and rice profit per plot were significantly higher on the tractor plots, while income and profit per hectare were also higher but not significantly so.

7. Estimated Effects of Mechanization

We use the DR method to estimate the effects of the use of tractors on the adoption of agronomic practices, the application of inputs, and agricultural performance. We control for the basic characteristics as well as for the season of cultivation.

Table 17 presents the estimation results for the effects of tractor use on the adoption of agronomic practices. As expected, tractor use significantly increased the number of adopted agronomic practices. In particular, it led to a substantially higher adoption of bund and canal construction but, unexpectedly, a slightly lower adoption of seed selection.

Table 18 presents the estimated effects of tractor use on the size of cultivated land and the application of labor and machinery. While tractor use was associated with greater cultivated land size and greater application of hired labor and machinery, the application of family labor did not change significantly.

To understand these results more thoroughly, Tables 19 and 20 present the application of family labor and hired labor, respectively, across different tasks. Although the estimates were not statistically significant, the coefficients suggest that tractor use tended to increase the application of family labor in crop care, but reduce the application of family labor in land preparation, crop establishment, and crop harvest. Notice that crop care includes the application of fertilizer and chemicals and water control, for which the family's care and judgement are important (Hayami and Otsuka 1993). Tractor use led to a substantial increase in the application of hired labor in crop establishment and harvesting, which are simpler and easier to monitor than is crop care. As may be expected, tractor use is associated with an increase in hired labor in crop care, though to a much lesser extent.

Finally, Table 21 presents the estimated effects of tractor use on paddy prices, yields, and incomes and profits from rice farming. Tractor use significantly increased paddy prices, rice yields, rice income per plot, and rice profit per plot, consistent with the greater adoption of improved agronomic practices. For example, as we observed in Table 20 that tractor use increased the application of hired labor in not only harvesting per se, but also threshing and drying. Appropriate drying is critical to improve the quality of paddy, and thus tractor use led to higher paddy price. Tractor use also increased income and profit per hectare, but the estimated effects are not statistically significant.

Overall, tractor use increased the cultivated land size, induced the adoption of agronomic practices by applying more labor and capital, and increased paddy prices, productivity, and profitability. These results support hypotheses M1 to M3 and are also in line with Takeshima et al. (2013), who found that households showing greater tractor use in crop production in Nigeria applied other inputs—such as fertilizer, seeds/chemicals, and hired harvesting labor—more intensively. As Pingali (2007) argued, our results also provide supporting evidence that the use of agricultural machinery does not necessarily reduce the demand for total labor in crop production. Taken together, these results shed light on the potentially complementary roles between agricultural machinery and labor in crop production in SSA, which have not been extensively investigated in conventional studies.

8. Conclusion

In sub-Saharan Africa, where the population is rapidly growing and uncultivated land is declining, farming intensification is important for addressing food security. This study analyzed the effects of CF in the promotion of intensive farming by overcoming potential failures in input markets and by providing technical services for rice farming. Using primary data drawn from Cote d'Ivoire, we compared the adoption of improved agronomic practices, input applications, and farming performance between CF and non-CF farmers. We found that CF failed due to an inability to secure tractors in a timely manner, which led to a lower application of labor and capital, reduced the adoption of improved agronomic practices, and lowered rice yields. We next examined the complementarity between the mechanization in land preparation and the intensification of farming by comparing the adoption of agronomic practices between farmers who used tractors and farmers who prepared their land manually. Tractor use may have saved labor in land preparation, but, more importantly, it also induced an intensification of the farming system and increased labor application, which more than offset the reduction in labor use in land preparation. In other words, a complementarity was revealed between mechanization and input- and labor-intensive farming.

These findings provide solid support for the emerging literature that suggests a positive association between mechanization and the adoption of intensive farming systems in sub-Saharan Africa (Takeshima et al, 2013, 2015; Pingali 2007). Based on our findings and those offered in the recent literature, we recommend that policies be developed for intensifying the farming system in sub-Saharan Africa by increasing the stable supply of decent tractor services. To do this, the government should (1) build an extension system that promotes not only the adoption of improved agronomic practices but also the use of tractors; (2) help develop a tractor service market by providing information on tractor quality through inspections; and (3) train mechanics in tractor repair.

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Table 1. Basic characteristics of farmers by CF status and timing of cultivation.

	CF		Non-CF	
	Pre-treat	Post-treat	Pre-treat	Post-treat
HH head female (=1)	0.10	0	0.06	0.02
	(0.30)	(0)	(0.25)	(0.16)
HH head age	46.7**	45.3	42.1	45.3**
	(12.0)	(12.7)	(11.8)	(10.6)
HH head any schooling (=1)	0.51**	0.60	0.68	0.56*
	(0.50)	(0.49)	(0.46)	(0.49)
Family size	10.39*	9.93	8.84	9.67
	(5.74)	(5.67)	(5.80)	(6.21)
No. practices trained in the past	7.27**	6.96	5.76	6.66
	(3.67)	(3.64)	(4.29)	(4.31)
ln asset (000 FCFA)	2.98***	3.41	3.74	3.86
	(1.03)	(1.43)	(1.64)	(1.61)
Obs.	68	33	104	104

Notes: The unit of observation is plot. Standard deviations are in the parentheses. We conducted the *t*-test of equality of means between each column against the third column, which presents the control plots in the pre-treatment period. ***, ** and * indicate statistical significance level of 1%, 5%, and 10%, respectively.

Table 2. Adoption of agronomic practices and fertilizer application by CF status and timing of cultivation.

	CF		Non-CF		DID
	Pre-treat (1)	Post-treat (2)	Pre-treat (3)	Post-treat (4)	Effect of CF {(2)-(1)}-{(4)-(3)}
No. adopted practices	4.70	3.69***	4.73	4.36*	-0.64*
	(1.77)	(1.26)	(1.69)	(1.43)	[p=0.087]
Levelling (=1)	0.70	0.72	0.77	0.66*	0.13
	(0.45)	(0.45)	(0.40)	(0.47)	[p=0.231]
Bund construction (=1)	0.69	0.54*	0.71	0.56**	0.00
	(0.46)	(0.50)	(0.45)	(0.49)	[p=0.990]
Canal construction (=1)	0.75	0.63	0.74	0.77	-0.15
	(0.43)	(0.48)	(0.44)	(0.41)	[p=0.190]
Seed selection (=1)	0.82	0.84	0.83	0.84	0.01
	(0.38)	(0.36)	(0.37)	(0.36)	[p=0.869]
Seed incubation (=1)	0.55	0.27***	0.60	0.55	-0.23**
	(0.50)	(0.45)	(0.49)	(0.49)	[p=0.048]
Transplanting (=1)	0.66	0.42**	0.67	0.63	-0.20
	(0.47)	(0.50)	(0.47)	(0.48)	[p=0.107]
Transplanting in row (=1)	0.51*	0.24	0.38	0.31	-0.20*
	(0.50)	(0.43)	(0.48)	(0.46)	[p=0.081]
Chemical fertilizer (kg/ha)	297.1*	225.5	265.6	230.6*	-36.6
	(106.2)	(183.7)	(104.4)	(184.12)	[p=0.361]
Obs.	68	33	104	104	

Note: Standard deviations are in the parentheses, and *p*-values are in the brackets. We conducted the *t*-test of equality of means between each column against the third column, which presents the control plots in the pre-treatment period. ***, ** and * indicate statistical significance level of 1%, 5%, and 10%, respectively.

Table 3. Cultivated land, family labor use, cost of hired labor, and machinery cost by CF status and timing of cultivation.

	CF		**Non-CF**		**DID**
	Pre-treat (1)	Post-treat (2)	Pre-treat (3)	Post-treat (4)	Effect of CF {(2)-(1)}-{(4)-(3)}
Cultivated land size (Ha)	0.75	0.64*	0.80	0.76	-0.07
	(0.43)	(0.35)	(0.46)	(0.52)	[p=0.530]
Family labor (person-days/ha)	153.35***	63.02*	102.27	64.94***	-53.0*
	(140.94)	(109.92)	(97.92)	(83.07)	[p=0.063]
Hired labor cost (000 FCFA/ha)	68.40***	13.13***	115.70	69.97***	-9.54
	(69.45)	(29.00)	(100.8)	(87.12)	[p=0.781]
Machine cost (000 FCFA/ha)	111.26***	20.09**	68.21	29.74***	-52.7***
	(124.28)	(41.19)	(69.67)	(46.48)	[p=0.004]
Obs.	68	33	104	104	

Note: Standard deviations are in the parentheses. From columns (1) to (4), we conducted the *t*-test of equality of means between each column against the Column (3), which presents the control plots in the pre-treatment period. We also report the unconditional DID effect of CF in the last column, and the p-values in the brackets. ***, ** and * indicate statistical significance level of 1%, 5%, and 10%, respectively.

Table 4. The application of family labor across different farming tasks by CF status and timing of cultivation (in person-days/ha).

	CF		**Control**		**DID**
	Pre-treat (1)	Post-treat (2)	Pre-treat (3)	Post-treat (4)	Effect of CF {(2)-(1)}-{(4)-(3)}
Land preparation	27.80***	4.22***	13.35	8.56*	-18.79***
	(47.62)	(4.35)	(16.30)	(19.42)	[p=0.003]
Crop establishment	19.74	10.04	16.44	11.91	-5.17
	(28.11)	(12.35)	(22.22)	(28.77)	[p=0.337]
Crop care	56.68***	31.51	33.29	20.06***	-11.94
	(53.94)	(79.87)	(35.36)	(25.51)	[p=0.451]
Harvesting	46.00	16.79**	36.12	22.88**	-15.97
	(63.44)	(25.39)	(45.02)	(32.51)	[p=0.125]
Obs.	68	33	104	104	

Notes: Standard deviations are in the parentheses. From columns (1) to (4), we conducted the *t*-test of equality of means between each column against the Column (3), which presents the control plots in the pre-treatment period. We also report the unconditional DID effect of CF in the last column, and the p-values in the brackets. ***, ** and * indicate statistical significance level of 1%, 5%, and 10%, respectively.

Crop establishment consists of seeding and transplanting. Crop care includes weeding, fertilizer application, pesticide and herbicide application, and water control. Harvesting consists of not only harvesting but also threshing and drying.

Table 5. Cost of hired labor across different farming tasks by CF status and timing of cultivation (in 1000 FCFA/ha).

	CF		**Non-CF**		**DID**
	Pre-treat (1)	Post-treat (2)	Pre-treat (3)	Post-treat (4)	Effect of CF {(2)-(1)}-{(4)-(3)}
Land preparation	10.78*	0.48**	22.89	7.67***	4.92
	(20.48)	(2.78)	(49.59)	(23.02)	[p=0.676]
Crop establishment	28.35*	3.33***	36.48	13.68***	-2.22
	(30.06)	(13.38)	(32.37)	(25.30)	[p=0.707]
Crop care	11.17	0.57**	12.96	8.95	-6.59
	(26.47)	(3.28)	(27.15)	(20.33)	[p=0.157]
Harvesting	16.74***	7.68***	38.77	31.33	-1.62
	(28.94)	(16.49)	(49.87)	(56.44)	[p=0.852]
Obs.	68	33	104	104	

Notes: Standard deviations are in the parentheses. From columns (1) to (4), we conducted the *t*-test of equality of means between each column against the Column (3), which presents the control plots in the pre-treatment period. We also report the unconditional DID effect of CF in the last column, and the p-values in the brackets. ***, ** and * indicate statistical significance level of 1%, 5%, and 10%, respectively.

Crop establishment consists of seeding and transplanting. Crop care includes weeding, fertilizer application, pesticide and herbicide application, and water control. Harvesting consists of not only harvesting but also threshing and drying.

Table 6. Cost of machinery use across different farming tasks by CF status and timing of cultivation (in 1000 FCFA/ha).

	CF		Non-CF		DID
	Pre-treat (1)	Post-treat (2)	Pre-treat (3)	Post-treat (4)	Effect of CF {(2)-(1)}-{(4)-(3)}
Land preparation	54.22*	13.52**	40.88	22.43***	-22.25**
	(44.71)	(27.69)	(42.59)	(36.03)	[p=0.014]
Harvesting	57.03*	6.56*	27.32	7.31***	-30.46**
	(115.05)	(16.18)	(52.14)	(27.98)	[p=0.048]
Obs.	68	33	104	104	

Note: Standard deviations are in the parentheses. From columns (1) to (4), we conducted the *t*-test of equality of means between each column against the Column (3), which presents the control plots in the pre-treatment period. We also report the unconditional DID effect of CF in the last column, and the p-values in the brackets. ***, ** and * indicate statistical significance level of 1%, 5%, and 10%, respectively.

Table 7. Paddy price, yield, income, and profit by CF status and timing of cultivation (in FCFA for rice price & in 1000 FCFA/ha for the rest).

	CF		**Non-CF**		**DID**
	Pre-treat (1)	Post-treat (2)	Pre-treat (3)	Post-treat (4)	Effect of CF {(2)-(1)}-{(4)-(3)}
Paddy price	182.35	184.09	186.00	173.41**	14.33
	(89.23)	(31.75)	(37.78)	(36.07)	[p=0.277]
Rice yield	4.27	3.93	3.95	4.07	-0.46
	(2.28)	(1.93)	(1.54)	(1.98)	[p=0.348]
Rice income	382.81	555.75*	398.96	521.33**	50.57
	(715.31)	(374.61)	(443.14)	(330.59)	[p=0.676]
Rice profit	152.78	461.22**	245.54	423.91***	130.07
	(720.65)	(421.62)	(467.99)	(349.40)	[p=0.307]
Obs.	68	33	104	104	

Note: Standard deviations are in the parentheses. From columns (1) to (4), we conducted the *t*-test of equality of means between each column against the Column (3), which presents the control plots in the pre-treatment period. We also report the unconditional DID effect of CF in the last column, and the p-values in the brackets. ***, ** and * indicate statistical significance level of 1%, 5%, and 10%, respectively.

Table 8. Determinants of implementing improved agronomic practices and fertilizer application. (DR method)

	No. of adopted practices	Leveling (=1)	Bund (=1)	Canal (=1)	Seed selection (=1)	Seed incubation (=1)	Transplant (=1)	Transplant in row (=1)	Fertilizer (kg/ha)
(1) CF *Pre-Treat	-0.33	-0.09	-0.03	-0.05	-0.09	-0.18**	-0.009	0.13	31.40*
	(0.33)	(0.08)	(0.07)	(0.08)	(0.07)	(0.09)	(0.09)	(0.09)	(17.14)
(2) CF *Post-Treat	-1.20***	0.05	-0.11	-0.17	0.003	-0.47***	-0.29***	-0.21***	-55.76*
	(0.26)	(0.07)	(0.11)	(0.11)	(0.07)	(0.08)	(0.10)	(0.07)	(31.12)
(3) Non-CF * Post-Treat	-0.36	-0.12**	-0.14*	0.03	0.02	-0.09	-0.01	-0.04	-27.28
	(0.25)	(0.06)	(0.07)	(0.06)	(0.05)	(0.07)	(0.07)	(0.07)	(28.95)
Control mean & se	4.74	0.82	0.72	0.75	0.80	0.62	0.64	0.34	272.66
	(0.17)	(0.04)	(0.04)	(0.04)	(0.04)	(0.05)	(0.05)	(0.05)	(11.45)
Effect of CF: (2)-(1)-(3)	-0.51	0.26**	0.06	-0.09	0.07	-0.20*	-0.271*	-0.30**	-58.66
χ^2_1 test of [(2)-(1)-(3)=0]	1.36	6.18	0.25	1.02	0.44	2.76	3.49	6.31	1.93
p-value	0.243	0.012	0.616	0.313	0.508	0.096	0.061	0.012	0.164

Note: Robust standard errors are in parentheses. ***, ** and * indicate statistical significance level of 1%, 5%, and 10%, respectively. We also controlled for the other characteristics.

Table 9. Determinants of family labor, hired labor, and machinery use. (DR method)

	Cultivated land size (ha)	Family labor per hectare (person-days/ha)	Hired labor cost per hectare (000FCFA/ha)	Machine cost per hectare (000FCFA/ha)
(1) CF *Pre-Treat	0.01	51.70**	-31.98***	45.82**
	(0.10)	(21.15)	(12.43)	(19.34)
(2) CF *Post-Treat	-0.26***	-29.87*	-102.41***	-58.23***
	(0.06)	(17.75)	(9.16)	(9.28)
(3) Non-CF * Post-Treat	-0.10*	-25.61**	-41.07***	-37.98***
	(0.06)	(12.53)	(12.44)	(7.97)
Control mean & se	0.90	81.59	111.43	73.96
	(0.04))	(10.13)	(8.65)	(6.31)
Effect of CF: (2)-(1)-(3)	-0.17	-55.96**	-29.36*	-66.07***
χ_1^2 test of [(2)-(1)-(3)=0]	2.41	4.41	3.62	9.91
p-value	0.12	0.03	0.05	0.001

Note: Robust standard errors are in parentheses. ***, ** and * indicate statistical significance level of 1%, 5%, and 10%, respectively. We also controlled for the other characteristics.

Table 10. Determinants of rice price, productivity and profitability. (DR method)

	Paddy price (FCFA/kg)	Rice yield (ton/ha)	Rice income (000FCFA/ha)	Rice profit (000FCFA/ha)
(1) CF *Pre-Treat	3.01	0.10	-40.83	-118.39
	(14.22)	(0.36)	(107.18)	(110.38)
(2) CF *Post-Treat	0.12	-0.54*	69.19	114.00*
	(6.40)	(0.30)	(69.19)	(69.04)
(3) Non-CF * Post-Treat	-10.76**	0.30	118.06*	156.48**
	(4.82)	(0.34)	(61.52)	(62.56)
Control mean & se	187.01	4.00	425.49	303.00
	(3.86)	(0.17)	(40.53)	(42.20)
Effect of CF: (2)-(1)-(3)	7.87	-0.94*	-8.04	75.91
χ_1^2 test of [(2)-(1)-(3)=0]	0.22	3.23	0.00	0.33
p-value	0.637	0.07	0.995	0.567

Note: Robust standard errors are in parentheses. ***, ** and * indicate statistical significance level of 1%, 5%, and 10%, respectively. We also controlled for the other characteristics.

Table 11. Basic characteristics of the non-CF farmers' plots by the use of tractor.

	Tractor	Manual
HH head female (=1)	0.04	0.04
	(0.21)	(0.21)
HH head age	43.8	43.7
	(10.3)	(12.2)
HH head any schooling (=1)	0.66	0.58
	(0.47)	(0.49)
Family size	10.0*	8.5
	(6.5)	(5.3)
Proportion of male adult members	0.33	0.32
	(0.18)	(0.16)
Proportion of female adult members	0.29	0.29
	(0.15)	(0.12)
Cultivate in July or later (=1)	0.42***	0.57
	(0.49)	(0.49)
No. of training attended by family	6.5	5.8
	(4.3)	(4.2)
ln asset (000FCFA)	3.82	3.77
	(1.7)	(1.4)
Land rent (000FCFA/ha)	11.9	5.6
	(40.6)	(12.3)
Water availability: "scarce" (=1)	0.01	0.03
	(0.13)	(0.19)
Water availability: "good" (=1)	0.19***	0.02
	(0.39)	(0.16)
Obs.	105	103

Note: Standard deviations are in the parentheses. ***, ** and * indicate statistical significance level of 1%, 5%, and 10%, respectively.

Table 12. Adoption of agronomic practices and fertilizer application among non-CF farmers by the use of tractor.

	Tractor	**Manual**
No. of adopted agronomic practices	4.85***	4.23
	(1.55)	(1.53)
Leveling (=1)	0.80***	0.64
	(0.40)	(0.48)
Bund construction (=1)	0.85***	0.41
	(0.35)	(0.49)
Canal construction (=1)	0.84***	0.66
	(0.36)	(0.47)
Seed selection (=1)	0.79**	0.89
	(0.40)	(0.31)
Seed incubation (=1)	0.63*	0.52
	(0.48)	(0.50)
Transplanting (=1)	0.61	0.68
	(0.48)	(0.46)
Transplanting in row (=1)	0.30	0.39
	(0.46)	(0.49)
Chemical fertilizer (kg/ha)	251.7***	149.3
	(171.8)	(158.0)
Obs.	105	103

Note: Standard deviations are in the parentheses. ***, ** and * indicate statistical significance level of 1%, 5%, and 10%, respectively.

Table 13. The application of family labor, hired labor, and machinery among non-CF farmers by the use of tractor.

	Tractor	Manual
Cultivated land size (ha)	0.91***	0.65
	(0.46)	(0.40)
Family labor (person-days/ha)	78.0	89.3
	(101.1)	(82.9)
Hired labor cost (000 FCFA/ha)	119.0***	61.0
	(90.7)	(95.6)
Machine cost (000 FCFA/ha)	82.6***	14.6
	(53.1)	(50.9)
Obs.	105	103

Note: Standard deviations are in the parentheses. *** indicate statistical significance level of 1%.

Table 14. The application of family labor across different tasks among non-CF farmers by the use of tractor.

	Tractor	Manual
Land preparation (person-days/ha)	9.1	12.8
	(21.0)	(14.2)
Crop establishment (person-days/ha)	13.4	14.9
	(30.7)	(19.5)
Crop care (person-days/ha)	26.7	26.5
	(32.7)	(32.7)
Harvesting (person-days/ha)	27.6	31.3
	(44.1)	(34.3)
Obs.	105	103

Notes: Standard deviations are in the parentheses.
Crop establishment consists of seeding and transplanting. Crop care includes weeding, fertilizer application, pesticide and herbicide application, and water control. Harvesting consists of not only harvesting but also threshing and drying.

Table 15. The cost of hired labor across different tasks among Non-CF farmers by the use of tractor.

	Tractor	**Manual**
Land preparation (000FCFA/ha)	14.3	16.2
	(40.7)	(37.9)
Crop establishment (000FCFA/ha)	36.6***	13.2
	(31.5)	(26.0)
Crop care (000FCFA/ha)	14.1*	7.7
	(23.5)	(24.1)
Harvesting (000FCFA/ha)	48.3***	21.4
	(61.2)	(39.5)
Obs.	105	103

Notes: Standard deviations are in the parentheses. * and *** indicate statistical significance level of 10% and 1%, respectively.
Crop establishment consists of seeding and transplanting. Crop care includes weeding, fertilizer application, pesticide and herbicide application, and water control. Crop harvest consists of harvesting, threshing, and drying.

Table 16. Rice price, yield, income, and profit among non-CF farmers by the use of tractor.

	Tractor	Manual
Paddy price (FCFA/kg)	185.3**	173.9
	(37.4)	(36.6)
Rice yield (kg/ha)	4.39***	3.62
	(2.01)	(1.39)
Rice income per ha (000FCFA/ha)	478.4	441.4
	(402.5)	(387.8)
Rice profit per ha (000FCFA/ha)	361.4	307.4
	(415.9)	(427.5)
Rice income per plot (000FCFA)	460.3***	300.5
	(515.1)	(334.4)
Rice profit per plot (000FCFA)	381.8**	232.3
	(519.6)	(340.8)
Obs.	105	103

Note: Standard deviations are in the parentheses. t-test is against the control plots in the pre-treatment period. ***, ** and * indicate statistical significance level of 1%, 5%, and 10%, respectively.

Table 17. Effect of mechanization in land preparation on adoption of agronomic practices among non-CF farmers. (DR method)

	No. of adopted practices	Leveling (=1)	Bund (=1)	Canal (=1)	Seed selection (=1)	Seed incubation (=1)	Transplant (=1)	Transplant in row (=1)	Chemical fertilizer
Tractor	0.57**	0.05	0.52***	0.17**	-0.13**	0.12	-0.05	-0.10	46.74
	(0.28)	(0.08)	(0.08)	(0.07)	(0.06)	(0.09)	(0.09)	(0.08)	(31.49)
Control mean & se	4.21	0.74	0.32	0.68	0.90	0.50	0.65	0.37	231.13
	(0.24)	(0.07)	(0.07)	(0.06)	(0.04)	(0.07)	(0.07)	(0.07)	(26.61)

Note: Robust standard errors are in parentheses. *** and ** indicate statistical significance level of 1% and 5%, respectively. The timing of cultivation and other basic characteristics are controlled.

Table 18. Effect of mechanization in land preparation on the application of family labor, hired labor, and machinery among non-CF farmers. (DR method)

	Cultivated land size (ha)	Family labor per hectare (person-days/ha)	Hired labor cost per hectare (000FCFA/ha)	Machine cost per hectare (000FCFA/ha)
Tractor	0.19**	-7.14	57.59***	63.56***
	(0.07)	(14.36)	(12.73)	(6.78)
Control mean & se	0.75	79.46	63.98	18.51
	(0.07)	(10.81)	(8.64)	(5.37)

Note: Robust standard errors are in parentheses. *** and ** indicate statistical significance level of 1% and 5%, respectively. The timing of cultivation and other basic characteristics are controlled.

Table 19. Effect of mechanization in land preparation on the application of family labor among non-CF farmers. (DR method)

	Land preparation (person-days/ha)	**Crop establishment (=1)**	**Crop care (=1)**	**Harvesting (=1)**
Tractor	-3.20	-1.73	2.31	-4.48
	(1.16)	(4.18)	(5.61)	(5.78)
Control mean & se	12.11	14.26	23.00	29.10
	(1.78)	(2.74)	(4.76)	(4.02)

Notes: Robust standard errors are in parentheses.
Crop establishment consists of seeding and transplanting. Crop care includes weeding, fertilizer application, pesticide and herbicide application, and water control. Crop harvesting consists of harvesting, threshing, and drying.

Table 20. Effect of mechanization in land preparation on the hired labor cost among non-CF farmers. (DR method)

	Land preparation (000FCFA/ha)	**Crop establishment (000FCFA/ha)**	**Crop care (000FCFA/ha)**	**Harvesting (000FCFA/ha)**
Tractor	4.92	23.19***	6.50**	21.39**
	(5.07)	(4.21)	(3.07)	(9.28)
Control mean & se	8.92	12.94	7.86	30.64
	(2.88)	(2.80)	(2.14)	(6.24)

Notes: Robust standard errors are in parentheses. *** and ** indicate statistical significance level of 1% and 5%, respectively.
Crop establishment consists of seeding and transplanting. Crop care includes weeding, fertilizer application, pesticide and herbicide application, and water control. Harvesting consists of not only harvesting but also threshing and drying.

Table 21. Effect of mechanization in land preparation on paddy price, productivity and profitability among non-CF farmers. (DR method)

	Paddy price (FCFA/kg)	**Rice yield (ton/ha)**	**Rice income per ha (000FCFA/ha)**	**Rice profit per ha (000FCFA/ha)**	**Rice income per plot (000FCFA)**	**Rice profit per plot (000FCFA)**
Tractor	8.47*	0.86***	40.71	51.43	134.04*	126.62*
	(4.83)	(0.28)	(55.58)	(58.44)	(72.78)	(73.35)
Control mean & se	177.15	3.62	450.75	331.55	348.03	279.55
	(3.58)	(0.20)	(37.28)	(43.11)	(56.04)	(57.83)

Note: Robust standard errors are in parentheses. *** and * indicate statistical significance level of 1% and 10%, respectively.

Abstract(in Japanese)

要約

サハラ以南のアフリカで農業の生産性を高めるためにきわめて重要なことは、適切な農耕法を普及させ、インプットをより積極的に投入するよう促して、農業システムを集約化することである。しかし、この地域では公的な農業普及システムが脆弱で、インプットやアウトプットの市場もうまく機能していない。こうした状況で、インプットや農業技術研修、販売サービスなどを提供する契約栽培（CF）は、市場の不完全性を克服するためのひとつの有望な方法であると期待されている。この可能性について検討するため、本稿ではコートジボワールにおけるコメ生産に関する CF の事例について分析した。それによると、トラクターの供給が不十分であることが大きな原因で、CF が農業システムの集約化に結びついていないことがわかった。さらに分析したところ、トラクターの使用と労働投入との間には補完性があり、トラクターで整地すると、それに続く農作業ではインプットおよび労働集約的な農耕法が用いられ、労働の使用が増え、土地の生産性が向上することがわかった。これらの分析結果から、トラクターの普及は、サハラ以南のアフリカの稲作システムを集約化させるための鍵となる可能性が高いといえる。

キーワード：契約栽培、コメ生産、トラクター、農業の機械化、農業システムの集約化、緑の革命、サハラ以南のアフリカ、コートジボワール

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