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Sweet equality: Sugar, property rights, and land distribution in colonial Java☆

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ABSTRACT

This article exploits a unique district-level dataset to investigate the relationship between sugar cultivation, property rights systems and land distribution in colonial Java around the turn of the twentieth century. We demonstrate a negative and statistically significant relationship between sugar cultivation and the landholder Gini. An IV strategy, employing a newly computed index of sugar suitability as instrument, suggests that this effect is causal. It is argued that sugar production in the nineteenth and early twentieth centuries stimulated the expansion and persistence of communal landholding. This communal landholding consequently led to more equally distributed plots among landholders in the early twentieth century. We emphasize the importance of local property rights institutions in mitigating the effects of export production on socioeconomic outcomes.

1. Introduction

High within-country economic inequality is one of the major societal challenges facing the world today (UNDP, 2019). For developing countries especially, high degrees of economic inequality tend to be a source of concern and scholars have observed the negative effects of inequality and economic development (Easterly, 2007). Land is the primary source of wealth and income in agricultural societies and land inequality is shown to be negatively correlated with long-run economic growth (Deininger and Squire, 1998) and is generally associated with political and social inequality (Frankema, 2010: 418). For present-day Indonesia, it has been observed that landlessness and land inequality are important drivers of rural conflict and poverty (Bachriadi and Wiradi, 2011). Because land is often transferred from one generation to the next, land inequality tends to be highly persistent over time. Property rights regimes are fundamentally related to the distribution of land (Banerjee and Iyer, 2005; Piketty, 2020; Wegge, 2021). It is thus crucial to provide a better understanding of the determinants of land tenure systems and land distribution. In this article, we examine how

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sugar cultivation and colonial institutions influenced property rights and land distribution in colonial Java, Indonesia, around the turn of the twentieth century. In doing so, we also contribute to recent literature on the effects of the Cultivation System for long-run development in Java (Dell and Olken, 2020; de Zwart et al., 2022).

Geography, factor endowments and colonial institutions have often been put forth as major factors influencing inequality. In a seminal contribution, Sokoloff and Engerman (2000) suggest that the crops grown in a region have a crucial influence on inequality. Many cash crops, like sugar and tobacco, are most efficiently produced on large plantations which causes inequality to soar. Food crops like rice and wheat, on the other hand, are well-suited to smallholder production which allows for greater equalization of plots. Sugarcane is a labor-intensive crop that requires considerable amounts of cheap labor to be efficiently produced. In addition, raw sugarcane needs to be processed within days of the harvest in order to avoid rotting (Bosma, 2013). Consequently, sugar cultivation needs large capital investments to construct a sugar mill near the plantation. This combination of high capital investment and the need for a substantial amount of cheap labor is often associated with high levels of inequality. This view has been widely accepted and, influenced by Sokoloff and Engerman, Easterly (2007) exploits a measure of sugar suitability relative to grain suitability as an instrument for the level of economic inequality.

Williamson (2011; 2015) employs Heckscher-Ohlin trade theory to explain that land abundant tropical countries which specialized in the production of cash crops, like sugar, experienced higher inequality between landowners and landless wage laborers, because increased demand for land and capital pushed up rental-wage ratios. This pattern of specialization may also have increased the incomes of large landholders *vis-à-vis* small-scale peasants which led to the greater accumulation of land in the hands of large landowners and increased land inequality. Indeed, Williamson (2015: 36) notes that "globalization appears to have helped land concentration" in some parts of Southeast Asia after 1870. Colonial policies and institutions crucially influenced patterns of landholding. For colonial India, for example, it was observed that variations in colonial policies, land tenure, and taxation systems across India influenced the distribution of land (Banerjee and Iyer, 2005).

Recent research has shown that the relationship between geography, colonial export activities and economic outcomes was highly context specific and may have differed within single colonies (e.g., Bosma, 2019; Bruhn and Gallego, 2012; de Zwart, 2020; 2022). Bruhn and Gallego (2012) find that export industries that have often been considered "bad colonial activities", such as sugar production, were not always significantly related to higher levels of inequality. In this article, we show that this was also the case in colonial Java, where the effects of sugar cultivation were crucially mitigated by local land tenure arrangements. In Java, different systems of property rights to land coexisted in close vicinity to each other, including private and communal land tenure systems. These systems were also relatively flexible and changed over time. Colonial sugar cultivation stimulated communal landholding for two reasons. First, early nineteenth-century Java was labor scarce, and sugar was a labor-intensive crop (as also noted above). Because labor duties were levied only on those peasants who had access to land, there was an incentive to distribute lands widely throughout the population both for the colonial government (to increase the available pool of labor) and for the local peasantry (to decrease the individual forced labor burden). Second, towards the end of the nineteenth century, land became the scarce factor of production. Some communal land in Java consisted of plots that were periodically redistributed. Since sugar production exhausted the soil more than rice cultivation, the colonial sugar industry benefitted from periodic redistribution of plots as it allowed consistent access to replenished soils. Thus, because of the colonial sugar industry's need for labor and fertile soils, the extent of communal tenure (with and without annual redistribution of lands) was stimulated. Communal systems of land tenure consequently led to more equally distributed plots.

Previous studies have already observed the potential of communal land tenures to equalize properties (Booth, 1988), while others have noted the tendency of the sugar industry to stimulate the existence of communal lands with rotating tenures (Breman, 1983; van Zanden and Marks, 2012). Yet no previous studies have tied these three factors together in one framework. Moreover, whether the Cultivation System led to increasing communal tenures and decreasing land inequality is still the subject of academic debate (Elson, 1994: 164–166). That Java became more equal over the nineteenth century has most famously been argued by Geertz (1963), who suggested that fast population growth across the island led to "shared poverty", but this has been disputed by more recent scholars (Booth, 1998: 98–99; 2016: 16–17; Breman, 2015: 339; Elson, 1994: 162–168; Hüsken, 1988: 80–84).

In this paper we show that both the extractive Cultivation System in the mid-nineteenth century and the private sugar industry in the late nineteenth century led to increased communal tenures with fixed and rotating shares and that, through this effect on property rights systems, forced and free sugar cultivation was negatively related to land inequality among landholders. Possibly because of the increased need for migrant labor to work in sugar by the early twentieth century, the relationship is not significant for land distribution when including the landless population. This paper is the first to exploit detailed district level data (for 368 districts) ca. 1900 to test this relationship in a formal quantitative framework. It is also the first to provide evidence that the effect of colonial sugar cultivation on the distribution of land among landholders was causal via the application of an instrumental variables (IV) approach using a sugar suitability index as instrument. This article does not go against the notion that sugar cultivation may have led to greater inequality in other parts of the world. On a global scale it remains possible – even plausible – that sugar production resulted in higher levels of economic inequality, given the crop's characteristics of demanding substantial amounts of unskilled labor and considerable capital inputs. Instead, we emphasize that local institutions, in this case those of property rights to land, crucially mitigate the effects of export production.

This paper proceeds as follows. In the next section, we will elaborate on the historical context of colonial Java: highlighting in detail the different systems of land tenure, the workings of the Cultivation System in the period between 1830 and 1870, and the development of the private sugar industry in the period thereafter. In Section 3, we will discuss the main sources and data used to estimate the relationship between sugar production, property rights and land inequality. Section 4 shows the results and Section 5 concludes.

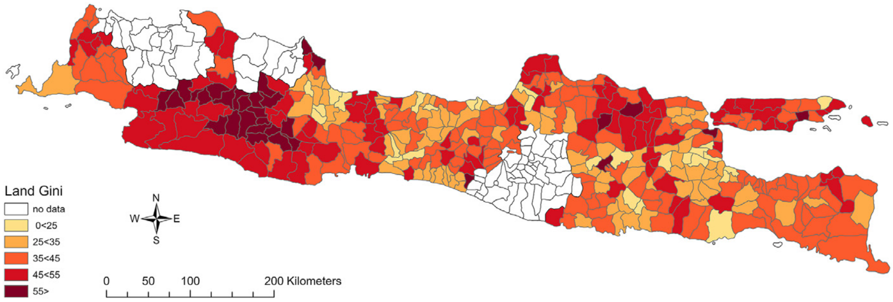

Fig. 1. Land inequality among landholders, 1903.
Sources: OMW 1903–1909.

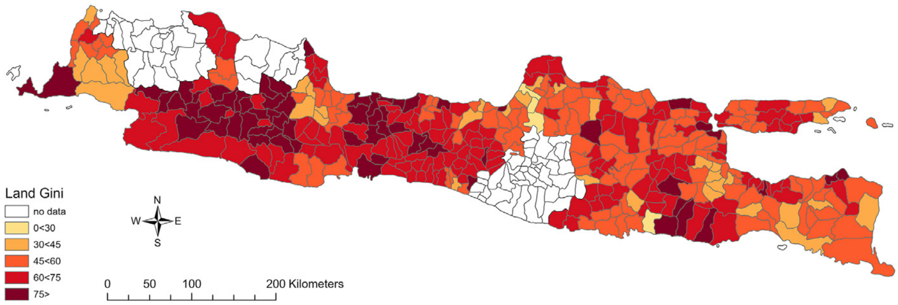

Fig. 2. Land inequality among population, 1903.
Sources: OMW 1903–1909.

2. Historical context

In nineteenth- and early twentieth-century Java there were essentially three types of property rights regimes with regard to land (Boomgaard, 1989; Kano, 1977). First, there was land held under private and heritable tenure. This land could generally be subdivided into smaller plots, bought and sold. In contrast to modern private property, however, there were often restrictions on who could become owner of the land. For example, the owner of the land had to be able to cultivate the land, or, otherwise, hire someone to do so. At times, no sale or purchase was allowed at all. This "ownership", or rather the "possession", of land, is perhaps better viewed as an exclusive, heritable, and commodified right to cultivate a plot of land, as the land was considered to be ultimately owned by the sovereign (in this case, the Colonial Government). For this reason, also in the case of private land tenures, rent was owed to the Government in the form of compulsory labor services and/or land taxes (the so-called *landrent*). Second, there were fixed communal tenures of land. Peasants obtained the right to cultivate a plot of what remained officially village lands. As a peasant would cultivate the same plot of land each year, and rights to this plot would be transferred from father to son, the main difference with private tenures was that the land could not be bought or sold, and could not be subdivided, or merged with other plots, without permission of the village authorities. Again, in return for the right to cultivate this plot, peasants had to perform labor duties. A third type of property consists of communal lands that were periodically redistributed. In this case, the plots of land of a village were redistributed among the village population (which could include newcomers), so that every peasant would cultivate a different plot each year. Again, in return for access to these rotating plots, peasants were liable for labor duties. These different types of property rights regimes to land could differ from one village to the next, but in general some broad geographical patterns can be observed: hereditary private property was the rule in West and East Java, communal tenures were more common in Central Java (see also Figs. 1 and 2 below). From the late nineteenth century on there has been discussion among colonial investigators about the extent to which communal tenures had been in existence prior to the start of the Cultivation System (discussed in Boomgaard (1989: 1–3). At present, however, there is "no doubt" that these systems co-existed already before 1800 (Boomgaard, 1989: 40; Kano, 1977: 166).

It is likely that the implementation of the Cultivation System caused changes in land tenure. In this system, Javanese peasants were forced to devote a substantial share of their labor and land to cultivate different cash crops – such as sugar, coffee, tobacco, cotton, and indigo – for the government in return for payments that were substantially below market value. Much of these payments also returned into government coffers in the form of land taxes owed by the peasants. This implied that a certain level of compulsion was needed to ensure compliance: "uncooperative peasants could find themselves arrested, whipped or stripped and exposed to the burning sun" (Elson 1985: 52). The colonial government set specific targets for the various cash crops that had to be produced in each residency (the largest administrative unit in the Netherlands East Indies), which then translated into targets at the district and village levels (de Zwart et al., 2022). The labor obligations to work in cash crop production were in principle levied on landowners or those with user rights to land. Because production targets were set at the village level, while labor duties fell on those with ownership or user rights to land, there was an incentive to distribute lands more widely among the village population. Although this applied to all crop production in the system, because sugar is a labor-intensive crop, especially when including the work on the immediate processing of the cane (van der Eng, 1996: 158–159) that was also part of the forced cultivation duties, one may expect these tendencies to be stronger for regions that produced sugar.

For these reasons, it has been widely noted that the Cultivation System spurred the increase in the amount of communal land, both with and without annual redistribution and that expansion of communal lands led to decreased inequality (Booth, 1988; Boomgaard, 1989). Elson (1994: 163–168), however, questions this. First, he doubts whether the Cultivation System led to a more equitable distribution of land, citing counteracting evidence such as observations from colonial officials who noted that the "lower classes" held "almost no *sawah*"[1], while village chiefs and other elites obtained very large plots. Second, he also disputes the extent to which the Cultivation System led to increasing communalisation of lands, as he argues that communal land was already well established prior to the creation of the system. In addition, he notes that there remained many areas without communal land and therefore that there was no single tendency towards increased communalization. Elson (1994) did not systematically analyze these differences and it is possible that different crops cultivated in the system would have had different consequences and that it was mainly sugar production that stimulated the communalization of plots.

The enactment of the Agricultural Law in 1870, which opened the East Indies for the establishment of private capitalist enterprise and ended the government monopoly on cash crop produce, has generally been seen as marking the end of the Cultivation System. Forced sugar and coffee cultivation actually continued after that: the last government sugar was produced in 1891, while coerced government coffee production ended only in 1917 (de Zwart, 2021; de Zwart et al., 2022). This caveat notwithstanding, the post-1870 period is known as the "liberal era" of the Dutch East Indies. In line with economic and political ideologies of the late nineteenth century, communal property rights systems were considered backward and the colonial government started to stimulate the adoption of private property rights.[2] The Dutch Minister of Colonies between 1863–66 and 1872–74, Fransen van de Putten, left little doubt about his opinions: "common property or possession (however one wants to call it) is a cancer that gnaws on the indigenous society of Java, that inhibits all further development and seriously hinders the prospering of country and people" (Nota, 1902: 2).[3] From 1864, the ministry started drawing up proposals for a decree that would allow for the conversion of communal land into privately held properties. The plans were revised several times and only made it to an official decree in 1885 (Staatsblad, 1885, no. 102). The decree made the conversion of communal into individual ownership possible if three-quarters of those with rights to the communal lands wanted it so (Staatsblad, 1885, no. 102).

Despite the decree, the conversion of communal lands into private plots developed very slowly: by 1907 still only 42 percent of the land in Java was held privately (Booth, 1988: 72). Both Breman (1983) and van Zanden and Marks (2012) suggest that the interests of the private sugar industry may have played a part in this lack of conversion: "[i]n the regions where the sugar industry continued to be active after the dissolution of the Cultivation System, these systems of periodic redistribution of the land continued to function, or were perhaps even reinforced" (van Zanden and Marks, 2012: 88). Because sugar cultivation exhausts the soil, it benefitted from periodic rotation. All the more so because the industry could try to exploit the power of village heads to allocate the best fields to them each year (Breman, 1983: 27). Finally, by the later nineteenth century there is evidence that those regions with a large sugar industry also attracted substantial numbers of labor migrants (Bosma, 2013: 127, 179, 187; Gallardo-Albarrán and de Zwart, 2021: 12; Knight, 1994: 68).

Based on this literature review, it can be postulated that greater involvement in sugar production during the nineteenth century (both under the government-controlled Cultivation System up to 1870 and by private sugar entrepreneurs thereafter) resulted in higher shares of land under communal tenure, which, in turn, resulted in more equally distributed plots in the early twentieth century. At the same time, labor migration in the later nineteenth century may have led to increased numbers of landless workers in sugar districts which may have raised the land Gini among population. In the remainder of this paper, we will assess quantitatively to what extent sugar production is associated with the degree of land inequality and the share of communal land across Java. In the next section, we will introduce the sources on which this investigation is based.

3. Sources and data

3.1. Sources

In Queen Wilhelmina's speech of 17 September 1901, which is generally viewed as the starting point of the so-called "Ethical Policy" in the Dutch East Indies, the announcement was made that the government would launch large-scale research into the causes of declining welfare on Java. The outcomes of this research, published in a total of 46 separate volumes, is now generally known as the Declining Welfare Report (and in Dutch: *Onderzoek Mindere Welvaart*, OMW for the remainder of this paper). The data needed to answer a questionnaire containing 533 questions on a wide range of topics (from landholding, rice prices, to crime rates, and the position of women) were to be collected locally by the civil servants. Filled out reports had to be sent directly to the Commission in charge of the Declining Welfare study (Hasselman, 1914: XVII-III). The study was concerned with almost all districts of Java, only the principalities of Yogyakarta and Surakarta were entirely excluded from the research.

[1] *Sawah* is a flooded field of arable land; often planted with rice.

[2] As was also the case in the British case, discussed by Anne Phillips (1989: 11-12).

[3] All English quotes of contemporaries are translations by the authors; original Dutch texts are available upon request.

The surveys were extraordinarily detailed and comprehensive and according to Hüsken (1994: 216), who worked with these figures, they provide a crucial overview of "living conditions and social organization of production in most of Java and Madura". The OMW study yielded so much data that it took C.J. Hasselman (1914) over a decade to write the final report. It is unlikely that the published reports were much influenced by colonial politics as the inquiry presented many different and even contradictory opinions on the extent and causes of poverty on the island. At the same time, it has been noted that the inquiries themselves were a hurried job as the time available for data collection had been only one year, a period that was considered by many to be too short (Hüsken, 1994: 216). A certain degree of error and noise in the data therefore must be taken into account. Such error, randomly distributed in the absence of bias, will make it harder to find significant results in Section 4 of this paper.

3.2. Land inequality

Figures on land inequality come from the various *Afdeelingsverslagen* (district reports) of the OMW (1903-1909). These reports note how many households were landless, and how many households held plots of varying sizes (in 15 classes, ranging from 0.25 *bouw* to over 35 *bouw*).[4] On the basis of these data, Ginis on land inequality in different districts can be computed. The results are plotted in Fig. 1. It shows that land inequality was comparatively high in West Java, and the mountainous region of Priangan (Gini >55) in particular. Additional pockets of high inequality can be found across the north coast of Cirebon and some parts of Rembang and Semarang. Lower levels of inequality are observed in central Java and east-central Java (in the residencies of Surabaya and Pasuruan). The source reports only differences in the size of plots and does not contain information on the value of those plots. It is possible that the Gini coefficient overstates inequality if the smaller plots are more fertile and productive than the larger plots. At the same time, it could also have been the case that the larger farmers also managed to obtain the best lands and that therefore the Gini based on size understates the true level of inequality (Vollrath 2007). This introduces some potential error in the inequality estimates.

There are blanks in Figs. 1 and 2. Besides the lacking data for Yogyakarta and Surakarta that were not included in the OMW, landholding figures for Batavia, Buitenzorg and Krawang are missing as most lands there were not in the hands of the Javanese population, but consisted of *particuliere landerijen* (private estates): lands that had been colonized by the Dutch East India Company in the seventeenth and eighteenth centuries and that were subsequently sold to European and Chinese private citizens. The Dutch colonial government held no direct control over these lands and did not collect any land taxes there (resulting in a lack of data about land registration).

The focus in this paper is on the distribution of land among landholders (similar to Frankema, 2010; Deininger and Squire, 1998). However, Vollrath (2007) rightly observed the land Gini may obscure inequality as a region where only a small number of people own very large plantations that are similarly sized will have relatively low land inequality, similar to a region that has a very large number of owners with equally-sized small plots. For this reason, we follow Erickson and Vollrath (2004, 2007) and include the total number of agricultural families relative to the total number of plots as control. Additionally, we also estimate the Land Gini among the total population of a district by adding the number of landless families in the Gini calculation with a plot sized 0 hectares (shown in Fig. 2).[5]

What does the distribution of land say about rural incomes in a region that has a lot of communal land? In areas with fixed communal tenures, this would imply more or less the same as when the land was privately owned, as the size of the plot to which a farmer held user rights would directly bear on the amount of rice he could cultivate, or how much money he would earn from renting out his land to sugar plantations (which paid a sum per *bouw*, which was, of course, also influenced by information about the fertility of the plot). In case of periodically redistributed land, the same would hold true, but a person could be assigned a different plot after a certain time, which may have been of a different size, so that these rotating plots influence long-term incomes of these peasants to lesser extent. The data suggests that the plots that fall under rotating tenures are all fairly similar in size (the average Gini among peasants with access to rotating lands across all districts is 24), so that the potential year-to-year changes for those peasants in terms of incomes from land due to rotation cannot be large. Moreover, there are just two districts that only have rotating lands and in all other districts peasants with user rights to rotating lands are living side by side with peasants that either own or have user rights to fixed plots. This implies that we can still say something about the overall distribution and access to lands across these different districts and that this distribution will significantly affect these peasants' livelihoods.

3.3. Sugar cultivation

For the main explanatory variable, data on sugar cultivation were collected from Colonial Reports (KVs) 1863 to 1871 and KVs 1893 to 1896. We look at figures on the share of land used for sugar cultivation relative to the total agricultural land in the periods 1866–70 and 1892–95, with the former years providing information on sugar cultivation under the Cultivation System, while the latter concern the first years of the private sugar industry. In addition, we gathered data on the total number of days of forced labor in sugar cultivation in 1862–63 (KV 1863) and on the total volume of sugar production in 1892–95 (KVs 1893-1896).[6] The accuracy

[4] 1 bouw = 0.71 ha.

[5] Also see Appendix A for a note on the landless population data.

[6] The years 1866 to 1870 are the first years for which these plantation-level sugar data were reported; the years 1892 to 1895 were chosen because in 1891 there were still government (Cultivation System) plantations in operation, and we could not use later years because the variable on the share of communal land is available only for 1895.

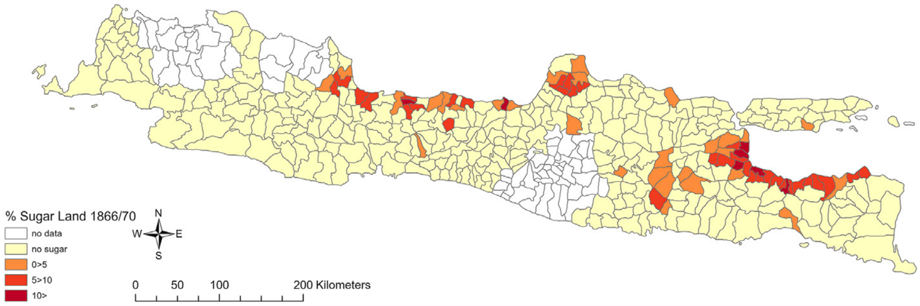

Fig. 3. Share of land used in sugar cultivation, 1866/70.
Sources: KVs (1867–1871).

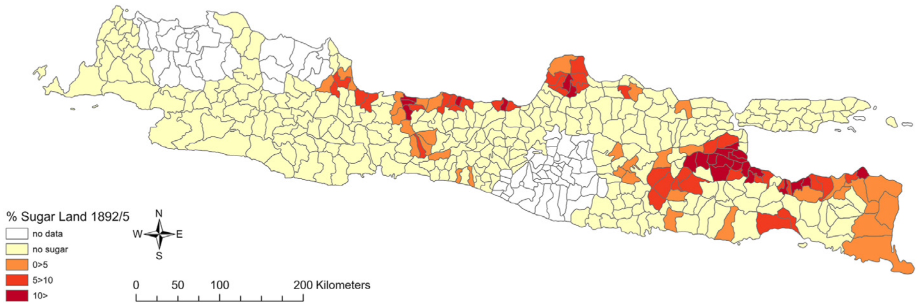

Fig. 4. Share of land used in sugar cultivation, 1892/95.
Sources: KVs (1893–1896).

of the sugar cultivation data can be considered high. Figures on sugar area and production were reported per plantation and sent to the government each year. We aggregated these data to the district level (see Appendix B for a list of districts that were merged or changed their names over the period between 1866 and 1903). For the 1920s, which is after the period we are concerned with in this paper, we have additional evidence that the sugar production data as reported in the KVs are reliable. First, one source explicitly notes that the recording of both the area and volume of production of private estates was very accurate (MSKS 1926). Second, for the 1920s, sugar production data from the KVs can be compared to those printed in the Landbouwatlas (1926) which shows almost identical spatial patterns with a correlation coefficient of 0.96 (Gallardo-Albarrán and de Zwart, 2021). If we assume that accuracy of these sugar data was not completely different a few decades earlier, these observations give additional confidence in these figures. Figs. 3 and 4

3.4. Property rights

Data on land distribution from the *Afdeelingsverslagen* of the OMW also provided information about whether plots in a district were individually owned or whether there were permanent user rights attached to it, versus plots that were redistributed. Additional data on the extent of communal tenure comes from the Colonial Report of 1895 (KV 1895), which printed a map with the percentage of land held under communal tenure (including fixed and rotating shares) in each district. The map was created by Karel Holle, honorary advisor to the colonial government, based on data supplied by local administrations. Figs. 5 and 6 show the district level data for (1) the percentage of all communal land and (2) the percentage of communal land with periodic redistribution of plots, respectively. Looking at Fig. 5, the spatial distribution of land tenure systems in Java around 1895 is as follows: in the West and East of Java, as well as the island of Madura, only privately held land existed. Across central Java the pattern is more mixed. There are many districts with between 80 and 100 percent of lands held under communal tenure, but also districts with only up to 40 percent communal land. A few districts in Central Java have no communal land at all. From Fig. 6 it becomes consequently clear that rotating lands were mainly located in the eastern parts of Central Java, in the residencies of Surabaya, Kediri, Rembang and Semarang (also see Fig. 7 below for the location of these residencies).

3.5. Control variables

In terms of controls, we gathered data on total population and average family size from the Declining Welfare Study. Together with figures on total agricultural land from that same source, these numbers also allowed to estimate population density per district ca. 1900. Additionally, we estimated the average distance of a district to a large city, harbor, and main road. To count as a large city, we looked at the figures of urban population sizes from Boomgaard and Gooszen (1991) including only those with populations

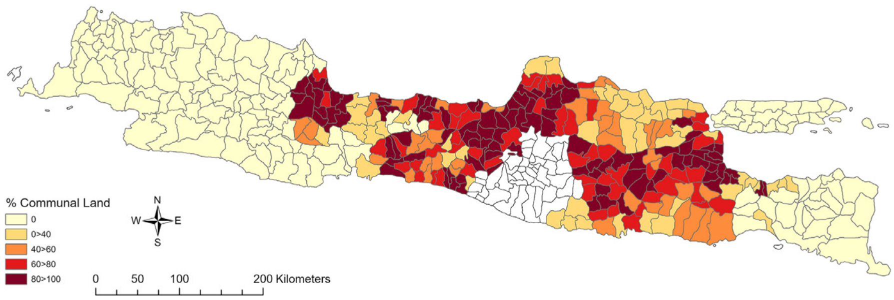

Fig. 5. Share of land under communal tenure, 1895.
Sources: KV1895. White areas imply no data.

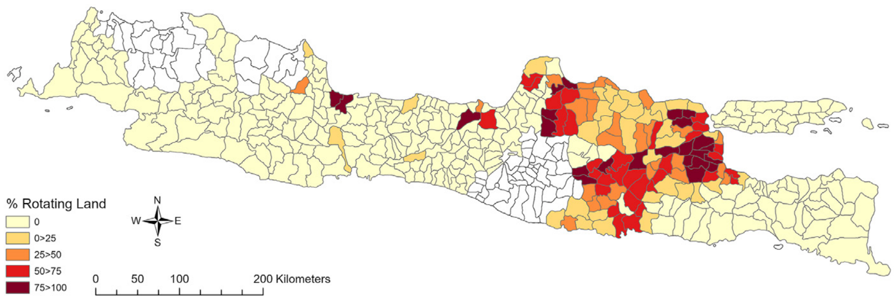

Fig. 6. Share of land under communal tenure with period redistribution, 1903.
Sources: OMW 1903–1909. White areas imply no data.

Table 1
Summary statistics. Sources: see text.

	Obs.	Mean	Std. dev.	Min	Max
Land Gini Landholders	368	40.31	10.41	14.75	70.14
Land Gini Population	368	62.13	13.07	17.22	95.27
% Communal Land	368	45.51	38.74	0	100
% Rotating Land	368	15.04	27.20	0	100
% Sugar land 1866/70	368	1.11	2.76	0	19.51
% Sugar land 1892/95	368	1.99	4.43	0	36.87
Log Sugar laborers 1862/63 + 1	368	1.76	3.88	0	11.37
Log Sugar production 1892/95 + 1	368	2.08	3.57	0	9.84
Sugar suitability index	368	3.77	1.13	1.06	5.99
Population/bouw agricultural land	368	6.13	5.15	1.16	63.79
Avg. family size	368	4.98	0.95	2.07	12.77
Total families/plots	368	1.86	1.03	0.59	9.71
Mean slope	368	9.78	7.23	0.81	30.47
Mean elevation	368	319.52	338.99	2.22	1487.60
Mean annual rainfall (mm)	368	2367.19	589.88	1209.46	3810.31
Ruggedness	368	72.81	157.34	0	1331.05
Mean distance to harbor (km)	368	65.92	37.66	3.54	167.76
Mean distance to main town (km)	368	34.32	23.88	3.54	129.31
Mean distance to main road (km)	368	13.53	15.21	1.34	87.01

above 5000. For main road we took a scanned map of Java in 1884 showing the main road system as printed in KV 1885. Geographic controls in the OLS analyses include mean altitude, slope, and rainfall in a district (data from 1970–2000) (CSI, 2019; Fick and Hijmans 2017) as well as average ruggedness (Nunn and Puga, 2012). Table 1 gives the summary statistics for the variables used in this paper.[7]

Finally, in what follows, we will exploit qualitative observations of the investigators of the Umbgrove Commission. This commission was specifically tasked to find out to what extent sugar cultivation altered social and economic conditions in Java in the 1850s.[8]

[7] De Zwart and Soekhradj (2023) contain all data and code needed to replicate the analyses shown in this paper.

[8] Dutch National Archives (DNA) 1858, The Hague. Archives of the Commission for the Recording of the Various Sugar Factories (Umbgrove Commission) inv. 2.10.11.

Table 2
OLS estimation of relationship between sugar cultivation and land Gini. Sources: see text.

	Dependent variable: Land Gini among Landholders						Dependent variable: Land Gini among Population					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
% Sugar land 1866/70	−1.012*** (0.227)	−0.928*** (0.21)	−0.628*** (0.227)				−0.399 (0.326)	−0.496* (0.296)	−0.223 (0.304)			
% Sugar land 1892/95				−0.674*** (0.157)	−0.493*** (0.149)	−0.444*** (0.158)				−0.175 (0.226)	−0.314* (0.182)	−0.131 (0.186)
Demogr. & distance controls	NO	YES	YES	NO	YES	YES	NO	YES	YES	NO	YES	YES
Geographic controls	NO	NO	YES	NO	NO	YES	NO	NO	YES	NO	NO	YES
Observations	368	368	368	368	368	368	368	368	368	368	368	368
Clusters	72	72	72	72	72	72	72	72	72	72	72	72
R-squared	0.072	0.095	0.169	0.082	0.125	0.175	0.007	0.218	0.266	0.004	0.219	0.265

Standard errors are in parentheses. Errors clustered at regency level.
*** $p < .01$, ** $p < .05$, * $p < .1$.

In addition, we looked at a series of primary archival documents in which high-level colonial officials who discussed the reasons for the lack of conversion to private property rights in the 1890s.[9]

4. Sugar cultivation, property rights and land distribution

4.1. Sugar cultivation and land distribution

We will develop our analyses in four steps. First, we will analyze to what extent sugar cultivation was *directly* associated with land distribution. Second, we will assess whether this relationship was causal by using a sugar suitability index in an instrumental variables framework. After that, we will assess how sugar cultivation was related to patterns of land tenure in terms of the share of communal land and the share of rotating lands. Finally, we establish the link between land tenure systems and land distribution.

How did sugar cultivation influence land distribution in Java around 1900? To answer this question, we run the following model:

$$Land\ Inequality_i = \alpha + \beta_1 \%Sugar\ Land_i + X'_i\gamma + \varepsilon_i \tag{1}$$

where *i* indices district, *Land Inequality* concerns two measures of land distribution: we look at either the Land Gini among landholders or the Land Gini among the entire population. *%Sugar Land* represents two different variables related to sugar cultivation: looking either at the share of sugar land relative to total agricultural land in 1866/70 or that share in 1892/95. *X'* is a vector of district level controls including demographic variables (population density per agricultural land, total number of families per number of plots, and avg. family size), distance variables (mean distance to big city, to harbor, and to main road, in kilometres), and geographic controls (average altitude, slope, annual rainfall and ruggedness).[10] Table 2 gives the results of running the model using data introduced in the previous section. Errors are clustered at the regency level to account for spatial correlation.

From Table 2 it becomes clear that the share of sugar land both during the cultivation system (1866–1870) and later during the period of the private sugar industry (1892/95) was negatively (and statistically significant) related to the Land Gini among landholders. Stepwise adding demographic, distance, and geographic controls, shows that the coefficient is somewhat reduced, but the relationship remains highly significant. Looking at the specification with all controls included (columns 3 and 6), it can be observed that one percentage-point increase in the share of sugar land under the Cultivation System, reduced the Gini among landholders with 0.6 Gini points, while for the period of the private sugar industry, the size of the coefficient is reduced by half to about 0.3 Gini points. This more equal distribution of plots among landowners is also confirmed in records of the Umbgrove Commission, which analysed the effects of sugar cultivation on local development in the 1850s. For example, the report on Yossowilangoon plantation in Pasuruan (eastern Java) notes that "as every family shares equally in sugar labor duties, so do they share equally in sawah",[11] and in the report on Wonoredjo plantation, also in Pasuruan, it was observed that prior to sugar cultivation "there was an unequal distribution of farmland, and the burdens on the peasants were unevenly shared, against the current situation of evenly distributed lands and burdens".[12]

When looking at the correlation between the share of sugar land and the Land Gini among the entire population, the signs on all coefficients are also negative, but the coefficients are smaller and standard errors larger, resulting in insignificant results.

[9] Arsip Nasional Republik Indonesia (ANRI), Jakarta, Archives of the General Secretariat, Missives of the Governments Secretary: inv. 3790 MGS 1893-12-23/3192-3193.

[10] We also ran the model with average temperature which led to virtually identical results. Correlation between altitude and temperature =−.99 and including both in the same model causes multicollinearity. OLS results are robust to using Conley standard errors (100km, Bartlett function); results available upon request.

[11] NA 2.10.11, no. 55.

[12] NA 2.10.11, no. 57.

Table 3
OLS estimation of relationship between sugar cultivation and land Gini: Robustness Test. Sources: see text.

	Dependent variable: Land Gini among Landholders											
	Sample excluding districts without communal land						Sample excluding districts without sugar production					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
% Sugar land 1866/70	−0.711***	−0.713***	−0.568**				−0.485*	−0.307	−0.432*			
	(0.212)	(0.206)	(0.225)				(0.265)	(0.231)	(0.240)			
% Sugar land 1892/95				−0.471***	−0.411***	−0.408***				−0.347**	−0.244	−0.349**
				(0.129)	(0.142)	(0.142)				(0.151)	(0.150)	(0.137)
Demogr. & distance controls	NO	YES	YES	NO	YES	YES	NO	YES	YES	NO	YES	YES
Geographic controls	NO	NO	YES	NO	NO	YES	NO	NO	YES	NO	NO	YES
Observations	252	252	252	252	252	252	102	102	102	102	102	102
Clusters	52	52	52	52	52	52	37	37	37	37	37	37
R-squared	0.055	0.068	0.109	0.061	0.113	0.120	0.039	0.107	0.219	0.042	0.203	0.229

Standard errors are in parentheses. Errors clustered at regency level.
*** $p < .01$, ** $p < .05$, * $p < .1$.

These insignificant results may be the result of the fact that the sugar industry often attracted migrant workers from other regions (Bosma, 2013: 187; Gallardo-Albarrán and de Zwart, 2021), thereby increasing the number of landless workers in a district and pushing up the estimate of the Land Gini among the total population.

4.2. Robustness

We test to what extent the patterns we find are robust to changes in the sample. The focus here is on the landholder Gini because that is where we found a consistent relationship with sugar production in both periods. First, because our argument is concerned with the relationship between sugar and land distribution *through* its effects on communal land tenure, we first assess whether the link holds when we include only districts that have at least some communal lands. Table 3 shows that the relationship holds, and that the coefficients are within the same order of magnitude, even if slightly smaller. Secondly, we assess whether the relationship between sugar area and landholder Gini holds when including only districts that produce at least some sugar in the 1860s and/or 1890s. As expected, the coefficients decline also in this case, since we no longer consider the extensive margin of sugar production (the effect of moving from a district without any sugar to a district with at least one operational sugar plantation), but only the intensive margin (how much land is being used for sugar cultivation). This suggest that both the intensive and extensive margins of sugar production are important to understand land distribution among landholders in Java. In specifications (8) and (10) the relationship is even insignificant. In Appendix Table A3, we additionally investigate to what extent we find similar results if we take a different measure related to sugar production rather than only the share of sugar land. For the early 1860s (1862/863), we exploit data on total number of labor days in forced cultivation and for the early 1890s we focus on total sugar production. The results are similar as with the share of sugar land (Table 2): a significant and robust negative relationship between sugar production and landholder Gini, and a negative, but not always statistically significant, correlation with land Gini among the total population.

4.3. Instrumental variables analysis

Nothing can yet be said about the causality of this relationship as there are potential sources of endogeneity. Possibly, the sugar industry was established in those regions that had a significant share of land under communal tenures, because there it could benefit from the larger pool of potential sugar workers or profit from the annual rotation of fields. Additionally, in districts with a high degree of land inequality, wealthy landholders may have pushed for the formalisation of private property rights. Measurement error discussed above may further result in biased estimates.

To overcome endogeneity concerns, this article exploits the fact that sugar cultivation requires specific geographical and climatological conditions for optimal growth. The exogenous variation in the location of the sugar industry is captured by computing a new sugar suitability index for Java. To calculate sugar suitability (shown in Fig. 7), bins were created for temperature, rainfall, elevation, slope and soil pH based on Dippel et al. (2020) and texture from Jayasinghe and Yoshida (2010), to similarly create an index running from 1–8. Here we use the weights for each bin following Jayasinghe and Yoshida (2010) in the aggregate index (see Appendix Table A6). We use data on average annual temperature and rainfall in the period 1970–2000 (Fick and Hijmans, 2017), in combination with present-day figures on slope and altitude (CSI, 2019) and soil characteristics (ISRIC 2019). Resolution is 3 arcsecond and the figures were averaged at the district level. While climate and soils may have changed slightly between the late nineteenth and late twentieth centuries, it is unlikely to have altered the spatial distribution of suitability for crop cultivation. Indeed, the suitability index correspond well with the known spatial distribution of coffee and sugar production in the nineteenth century (see also Felgendreher et al., 2018; Dell and Olken, 2020).

Why built our own sugar suitability index, when similar indices are also available from the FAO (Fisher et al., 2021)? This is because indices based solely on climatic indicators, which are often preferred in this kind of research (e.g., de Haas 2021; Roessler et al., 2020), show little variation in sugar suitability across Java (as shown in Appendix D) and are therefore unsuited for the purposes of this

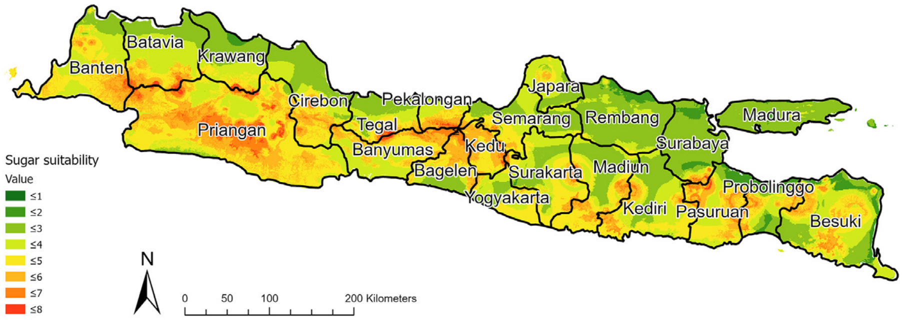

Fig. 7. Sugar Suitability across Java.
Sources: Dippel et al. (2020); Jayasinghe and Yoshida (2010).

Table 4
IV Regression explaining land inequality using sugar suitability as instrument. Sources: see text and Appendix.

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A:	**2SLS Gini among Landholders**					
% Sugar Land 1866/70	−1.878*	−1.692*	−1.508*			
	(1.043)	(1.002)	(0.913)			
% Sugar Land 1892/95				−1.188*	−1.081*	−0.970*
				(0.631)	(0.619)	(0.567)
Panel B:	**First Stage: % Sugar Land 1866/70**			**First Stage: % Sugar Land 1892/95**		
Sugar suitability	0.811***	0.755***	0.731***	1.281***	1.181***	1.136***
	(0.236)	(0.234)	(0.207)	(0.306)	(0.291)	(0.237)
Demographic controls	NO	YES	YES	NO	YES	YES
Distance controls	NO	NO	YES	NO	NO	YES
Observations	368	368	368	368	368	368
Clusters	72	72	72	72	72	72
First Stage F-Statistic	11.77	10.41	12.41	17.51	16.43	22.98
R^2	0.11	0.13	0.26	0.11	0.15	0.25

Robust standard errors are in parentheses. Errors clustered at regency level.
*** $p < .01$, ** $p < .05$, * $p < .1$.
SW F-Statistic. IV regressions using Stata's ivregress 2sls command.

paper. Additionally, the FAO suitability (agro-ecological attainable yield) indices are problematic for historical research, because these also contain information on current population distribution, land use and assumptions about farming techniques. As shown in Appendix D below, depending on what assumptions are taken in terms of inputs (high or low), the suitability for sugar cultivation is almost completely reversed. This raises doubts about usefulness of these figures for historical research on Java.

To establish the causal impact of sugar cultivation on land distribution, we estimate the following two-stages least squares model:

$$\%\ Sugar\ Land_i = \alpha_S + \beta_S Sugar\ suitability_i + X'_i \delta_S + \varepsilon_{Si}, \tag{2}$$

$$Land\ inequality_i = \alpha_L + \beta_L \%\ Sugar\ Land_i + X'_i \delta_L + \varepsilon_{Li}, \tag{3}$$

where the same applies as in model 1, with the addition of the sugar suitability variable introduced above and in Appendix D.[13] The vector of controls X' does not contain some of the geographic controls (elevation, rainfall, and slope) in the IV specification, because these variables are now part of the sugar suitability index,[14] but we continue to control for ruggedness and distance to towns and ports.

The results of running models 2 and 3 as shown in Table 4 suggests the share of sugar land can be instrumented using our newly constructed sugar suitability index based on geographical and climatic conditions in a district (all F-statistics are above 10). Furthermore, it is shown that the relationship between sugar cultivation and land inequality among landholders is causal. The coefficients change compared with the OLS and increase slightly, as is generally the case. When looking at the preferred specifications (3) and (6), it becomes clear that if the share of sugar land increases by 1 percentage point, this increases the landholder Gini by 1.5 Gini points

[13] We also ran the same regression with the FAO agro-ecological suitability index as instrument, but this resulted in insignificant results and an invalid instrument (low F-values). Results available upon request, see Appendix D for further details.

[14] The correlation between the sugar suitability index and geographic controls is high: with slope (r=−0.85), elevation (r=−0.84) and precipitation (r=−0.82). Including them in the regressions causes multicollinearity and leads to insignificant results.

Table 5
OLS estimation of relationship between sugar cultivation and communal lands. Sources: see text.

	Dependent variable: % Communal Land				Dependent variable: % Rotating Land			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
% Sugar Land 1866/70	4.378*** (0.793)	1.952*** (0.716)			2.742*** (0.917)	2.246*** (0.785)		
% Sugar Land 1892/95			2.867*** (0.552)	1.398*** (0.452)			1.849*** (0.638)	1.567*** (0.590)
Controls	NO	YES	NO	YES	NO	YES	NO	YES
Observations	368	368	368	368	368	368	368	368
Clusters	72	72	72	72	72	72	72	72
R-squared	0.097	0.401	0.107	0.406	0.077	0.318	0.091	0.329

Robust standard errors are in parentheses. Errors clustered at regency level.
*** $p < .01$, ** $p < .05$, * $p < .1$.

for sugar land in the late 1860s, or by almost 1 Gini point for sugar land in the early 1890s. Thus, Table 4 suggests that the benchmark regressions in the main analyses slightly underestimated the effect of sugar on the landholder Gini and that the relationship was not driven by endogeneity.

4.4. Mechanisms: land tenure systems

Given sugar production's potential tendencies to increase inequality, the puzzle remains *why* the correlation with land distribution among landholders was negative or absent. As argued above, this is best explained through sugar cultivation's relationship with land tenure systems. To investigate the extent to which sugar production was correlated with the share of communal and rotating lands, we run the following model:

$$\%Communal\ Land\ =\ \alpha\ +\beta_1 \%Sugar\ Land_i +\ X'_i\gamma +\ \varepsilon_i \tag{4}$$

where the same applies as in (1), but where $\%Communal\ Land$ concerns two outcomes: either the share of all communal land (that is both with fixed and rotating shares) in 1895, or the share of land under rotating tenures in 1903. Table 4 gives the results. To conserve space, we only show specifications with and without all controls; intermediate steps adding only demographic and or distance controls show (statistically significant) coefficients that are in between those reported here.

From Table 5, it becomes clear that there is a significant positive association between the share of agricultural land involved in sugar cultivation and the shares of communal and rotating lands. Looking at specifications with controls (2 and 6), it can be observed that each increase of the share of sugar land in 1866/70 by 1 percentage point is related to an increase in the share of communal land by 1.9 percentage points and an increase of 2.2 percentage points in the share of annually rotating lands. This effect is slightly larger than that for the share of land under sugar cultivation in 1892/5 where those numbers are 1.4 and 1.6 percentage points respectively (columns 4 and 8). Thus, the association between communal lands (whether rotating or not) and sugar cultivation was slightly stronger during the Cultivation System period. The relationship between sugar cultivation and communal tenures is highly robust to changes in the sample and changes in the measure of sugar cultivation (see Appendix C).

The positive link between sugar cultivation and the extent of communal tenure is also confirmed by qualitative observations from archival sources. In the report of the Umbgrove Commission on Langsee plantation (in Japara, Central Java) it is noted that "as a result of the implementation of the cultivations for the European market, changes took place in terms of the rights of local families in the sense that those families who according to ancient rights held a share in the village's common fields had to concede [part of those lands] to others who did not have those ancient rights to common fields."[15] Even clearer is the report on the sugar plantation of Wonoredjo in which it was observed that "sugar cultivation caused changes in the rights and duties of the population [...] as it became clear from the information received that prior to the implementation of sugar cultivation lands here were partially under individual tenure, whereas now the system of communal land is dominant".[16]

That sugar cultivation could also specifically stimulate annually rotating tenures is noted in the report on Kalimati plantation in Pekalongan (central Java) where they established:

> with certainty that previously there was no annual redistribution of rice fields and every *sikep* [peasant] was ensured to work the same *sawah* every year. Regarding this, the implementation of cash crop cultivation in general, and sugar cultivation in particular, caused a change, because those villages that have been assigned to sugar cultivation are forced to redistribute lands annually, whilst the other villages, either by their own choice, or stimulated by the government, have followed this practice.[17]

[15] NA, 2.10.11, inv. no. 28.
[16] NA, 2.10.11, inv. no. 57.
[17] NA 2.10.11, inv. no. 58.

Table 6
OLS Estimation of Relationship Between Communal Lands and Land Inequality. Sources: see text.

	Dependent variable: Land Gini among Landholders				Dependent variable: Land Gini among Population			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
% Communal Land	−0.156*** (0.020)	−0.186*** (0.018)			−0.088** (0.034)	−0.147*** (0.029)		
% Rotating Land			−0.139*** (0.022)	−0.164*** (0.019)			−0.125*** (0.030)	−0.096*** (0.028)
Controls	NO	YES	NO	YES	NO	YES	NO	YES
Observations	368	368	368	368	368	368	368	368
Clusters	72	72	72	72	72	72	72	72
R-squared	0.336	0.442	0.132	0.280	0.068	0.380	0.068	0.293

Robust standard errors are in parentheses. Errors clustered at regency level.
*** $p < .01$, ** $p < .05$, * $p < .1$.

While in the OMW it was written “that sugar cultivation is not conducive to fixed land tenure is an established fact and, as it now appears, has long been officially recognised and published, although in reports which have not attracted sufficient attention” (OMW; cited in Breman,1983: 25).

How is the share of communal land related to the distribution of land? As noted above, the expectation is that a larger share of land under communal tenure reduced tendencies towards land concentration. Nonetheless, this link is not automatic as elites may be able to capture a disproportionate share of common lands (see e.g., de Keyzer, 2019; Lesorogol, 2003; van Zanden, 1999). We investigate by running the following model:

$$Land\ Inequality = \alpha + \beta_1 \%Communal\ Land_i + X'_i\gamma + \varepsilon_i \tag{5}$$

where the same applies as in (1) and (4). In Table 6 it is shown that there is indeed a significant negative relationship between communal landownership and land inequality, also when accounting for a range of relevant control variables. Columns (2) and (6) suggest that the effect of a 1 percent increase in communal land (both fixed and rotating tenures) decreases land inequality among landholders by 0.19 Gini points and among the total population by 0.15 Gini points. This implies that the average difference between a district without any communal land and those consisting entirely of communal land is between 15 and 20 Gini points. Columns (4) and (8) show that the relationship between the share of rotating land and land inequality is similarly significant, although the coefficients are slightly smaller. This relationship is highly robust to changes in the sample.[18]

In the 1850s, the investigators of the Umbgrove Commission also observed that sugar cultivation, through its relationship with the communalization of lands, led to more equally distributed plots. The report on Langsee plantation in Japara, also cited above, notes that the increased number of people with a share in communal land had no negative consequences, as this “led the more privileged to have slightly less and the less privileged to have slightly more [land]”.[19] For the area around the plantation in Pangkah, Tegal, it was observed that:

> before the Cultivation System land was very unequally distributed, some were very wealthy, others owned no or very little land […] over time this changed as wealth was redistributed from the wealthy to the needy in a manner that would be cheered on only by socialists and communists. In the context of corvee and cultivation labor duties, however, these changes should be considered beneficial, as it provides the labourers with greater means of subsistence.[20]

Further evidence comes from an investigation from the year 1893 on the lack of conversion to private property after the 1885 decree. High level colonial officials hinted in their reports that this was related to the local population’s fears that an expansion of private property would concentrate landownership in the hands of the few. The Resident (highest official in a residency) of Japara (in central northern Java) observed “the population expects, not without reason, that it [the conversion to private tenures] will lead to a growing class of non-landowning families”. In the residency of Pasuruan, the Resident observed “the population fears that privately held tenures in general, through purchase and heritage will concentrate too much land in one hand”, while the Resident of Madiun (central-southern Java) wrote “the main argument against conversion used by the population is that they fear that labor duties [attached to the user rights to land] will not be spread sufficiently throughout the community.”[21]

Greater equality of plots allowed a larger number of peasants to have more substantial plots, which would directly impact the food they would be able to grow, or the income they would reap for renting it out. Whether this greater equality of plots also reduced political inequalities, as observed in the secondary literature on other cases, is more in doubt, however. It could even be the case that in those regions with more rotating lands, political inequality became greater as it vested a substantial degree of power in the local village chief who was charged with the annual redistribution of land. One report from the 1850s indeed suggests that the relationship

18 Results available upon request.
19 NA 2.10.11, no. 28.
20 NA 2.10.11, no. 102.
21 All quotes from: ANRI 3790 MGS 1893-12-23/3192-3193.

between village heads and inhabitants changed because of sugar cultivation, and that the former increasingly came to extort the latter.[22] Yet another report finds that in an area that already had communal land with rotating shares, sugar cultivation:

> ended the unjust practice in existence prior to the implementation of sugar cultivation where the village head distributed the fields in a manner disadvantageous to the population as he gave himself the largest and biggest share and distributed the remainder of fields randomly. It is this more equal distribution of plots that reconciled the peasants with the previously hated sugar cultivation.[23]

For the post-Cultivation System era, it has been suggested that in those areas with sugar factories there was substantial pressure on peasants, from both the sugar industry and the local village elites, to rent out their lands to the sugar interests (Breman, 1983). Moreover, Van der Eng (1996: 219–224) calculated that for peasants with access to land, the annual returns from leasing out their plots to the sugar industry were substantially higher than using those lands for subsistence rice production.

These analyses make clear that while the *direct* relationship between sugar cultivation and land distribution among the entire population was not always significant, the mechanisms relating both sugar cultivation to communal land, and communal land to inequality, were. This alludes to the *indirect* relationship between sugar cultivation and land distribution, and the importance of land tenure as crucial mediating variable impacting this relationship.

5. Conclusion

Land is the basic source of wealth and income in agricultural societies and it is therefore crucial to better understand the factors that influence its distribution. This article investigated the effects of colonial sugar production on land distribution in Java. We found a statistically significant negative relationship between sugar cultivation and landholder Gini and we demonstrated that this link was causal by using a sugar suitability index. The relationship between sugar cultivation and land inequality among the total population was also negative, but not statistically significant. The reduced strength of the correlation between sugar cultivation and land distribution among total population likely results from the fact that districts with more sugar cultivation also drew more migrants from the later nineteenth century on, which increased the landless population in a district. In terms of mechanisms, we highlighted the role of communal land tenure systems in mitigating the relationship between sugar cultivation and land distribution. The observed relationships in the quantitative data were confirmed by qualitative observations from colonial investigators and officials.

It is important to note that analyses of the effects of land inequality and/or communal rights for economic development in Java are outside the scope of this research. Recent literature on colonialism and inequality suggests the harmful economic and social effects of high inequality (e.g., Acemoglu et al., 2001; Easterly, 2007; Sokoloff and Engerman, 2000; Piketty, 2020). For colonial Java, it is unclear whether this was also the case. At least for some areas it was observed that rotating tenures led to greater extortion of the population by local heads in the mid-nineteenth century. For the later nineteenth century it has been suggested that peasants in sugar suitable areas were pressured by the sugar industry and local village chiefs to rent out their lands to the sugar plantations. Thus, while plots may have been more equally distributed in these areas, the peasants could have experienced less freedom than in other areas. Furthermore, following North (1990) and de Soto (2000) it may also have been the case that fewer plots held under private tenure resulted in negligence of the fields and reduced labor and capital investments in agricultural production, which could have lowered overall agricultural productivity. Future research may investigate how communal rights and land inequality were related to agricultural productivity measures and wider economic conditions and living standards. In this article, however, we have demonstrated the importance of local land tenure arrangements in determining the effects of geography and export production on socioeconomic outcomes.

Declaration of Competing Interest

None.

Data availability

Data and code have been made available on OpenICPSR.

Appendix

A: Note about computing Land Gini for entire population

For computing the Gini including the number of landless populations we generally took the number of landless as given in the OMW. In a few cases the number of “landless” was missing from the source, and in those cases, we took the number of families in the district from the population counts (average of the figure for 1900 and 1905) and subtracted the number of landowners from this. This concerns the districts (names as in sources) as shown in Table A1.

[22] NA 2.10.11, no. 37; in NA 2.10.11, no. 80, the whole practice of annual redistribution is considered “torture” of the local population.
[23] NA 2.10.11, no. 73.

Table A1
Districts without data on "landless". Sources: OMW (1903-1909).

Residency	Regency	District
Bantam	Pandegelang	Tjibalioeng
Kediri	Toeloengagoeng	Kalangbret
Kediri	Toeloengagoeng	Ngoenoet
Kediri	Toeloengagoeng	Tjampoerdarat
Kediri	Toeloengagoeng	Toeloengagoeng
Semarang	Grobogan	Grobogan
Semarang	Grobogan	Poerwodadi
Semarang	Pati	Kajen
Semarang	Pati	Telogowoengoe
Soerabaja	Grisee	Goenoengkendeng

B: Note about border changes and aggregating districts

We take data from several different sources, spanning a period of about 40 years. During this period there were some changes in borders (as well as some name changes of districts). The way we dealt with this is by aggregating the values to the largest unit. The main cost of this approach is the loss of observations. This applies to the districts (names as in sources) shown in Table A2.

Table A2
Merged districts and name changes.

Residency	District	Merger / name change
Besoeki	Rogodjampi	Rogodjampi & Genteng
Besoeki	Mlandigan	Mlandigan & Wringin
Besoeki	Sitoebondo	Sitoebondo & Kapongan
Cheribon	Palimanan	Palimanan & Ploembon
Cheribon	Tijawigebang	Tijawigebang & Lebakwangi
Cheribon	Telaga	Telaga & Madja
Kediri	Ngandjoek	Ngandjoek, Berbek & Gemenggeng
Kediri	Ngadiloewih	Djambeang
Kediri	Pare	Pare & Soekoredjo
Kediri	Karangan	Karangan, Trenggalek & Ngasinan
Kediri	Poele	Ngarjoen
Kedoe	Rowokele	Banjoemoedal
Kedoe	Ngadisono	Kaliworo
Madioen	Madioen	Bagi
Madioen	Parang	Plaosan and Parang
Madioen	Ngawi	Sepreh & Kenitan
Madioen	Ngrambe	Sine, Djogorogo & Ngambé
Madioen	Patjitan	Patjitan & Semanten
Madioen	Poenoeng	Pringkoekoe
Pasoeroean	Bangil	Kota Bangil & Gemping
Pasoeroean	Gending	Gending & Padjakaran
Pasoeroean	Kraksaän	Djabon & Kraksaän
Pasoeroean	Grati	Grati & Kedawoeng & Winongan
Pasoeroean	Pasoeroean	Kota Pasoeroean, Kraton, & Redjasa
Pasoeroean	Wangkal	Wangkal, Wonoredjo & Ngempit
Pekalongan	Kedoengwoeni	Sawangan and Pekadjangan (50%, only for sugar 1866/70)
Pekalongan	Paninggaran	Sawangan and Pekadjangan (50%, only for sugar 1866/70)
Pekalongan	Wiradesa	Sragi
Pekalongan	Adiwerna	Krangdon
Pekalongan	Boemidjawa	Boemidjawa and Boemiajoe
Pekalongan	Djatinegara	Djatinegara & Gantoengan
Pekalongan	Soeradadi	Maribaija
Priangan	Bandoeng	Oedjoengbroeng Koelon
Priangan	Oedjoengbroeng	Oedjoengbroeng Wetang
Priangan	Soreang	Koppo
Priangan	Tjikalong-wetan	Radjamandala
Priangan	Tjililin	Rongga
Priangan	Tjimahi	Tjilokotot
Priangan	Tjiparaj	Tjipeudjeuh
Priangan	Tjidewej	Tjisondari
Priangan	Bajongbong	Timbanganten

(continued on next page)

Table A2 (*continued*)

Residency	District	Merger / name change
Priangan	Boengboelang	Kandagwesi
Priangan	Leles	Tjikemboelan
Priangan	Pameungpeuk	Negara
Priangan	Tjibatoe	Wanakerta
Priangan	Tjikadang	Batoewangi
Priangan	Trogong	Panembong
Priangan	Soekaboemi	Soenoeng Parang
Priangan	Tjibadak	Tjimahi
Priangan	Karangnoenggal	Soekaradja & Karang
Priangan	Manondjaja	Pasir Pandjang
Priangan	Pangandaran	Padaherang
Priangan	Singaparna	Singaparna & Panjeredan
Priangan	Tjiawi	Tjiawi & Indibiang
Priangan	Tjikatomas	Mandala
Priangan	Tjimalaka	Tjibeureum
Priangan	Tomo	Tjonggean
Priangan	Patjet	Tjipoetri
Priangan	Sindangbarang	Tjidamar
Priangan	Soekanegara	Djambang-wetan
Priangan	Tjiandjoer	Maleber
Priangan	Tjibeber	Tjikondang & Peser
Priangan	Tjikalong-koelon	Tjikalong
Priangan	Tjirandjang	Tjihea
Semarang	Bangsri	Banjaran
Semarang	Petjangaän	Majong
Semarang	Kendal	Kendal & Perboean
Semarang	Weleri	Troeko
Semarang	Tajoe	Mergotoehoe
Semarang	Telogowoengoe	Sellowissi
Semarang	Padoeroengan	Srondol
Soerabaja	Djombang	Djombang & Modjoredjo
Soerabaja	Ngoro	Bareng
Soerabaja	Ploso	Ploso and Modjodadi
Soerabaja	Modjosari	Modjosari, Modjosari-kidoel & Modjosari-lor
Soerabaja	Goenoengkendeng	Rawapoeloe II
Soerabaja	Krian	Djenggolo IV
Soerabaja	Porong	Rawapoeloe I
Soerabaja	Sidoardjo	Djenggolo II
Soerabaja	Gedangan	Djenggolo I
Soerabaja	Boelang	Djenggolo III

C: Additional Robustness Tests

In Table A3 we test whether the main results hold when taking a different measure of sugar cultivation; looking (1) at the log of days laboured in sugar in the years 1862/63 and (2) the log of total sugar production in 1892/95. We test the robustness of the mechanisms in Tables A4 and A5. In Table A4 we check whether the results of the OLS on mechanisms are dependent on the sample by looking at samples containing only sugar-producing districts or only districts with at least some communal land. We check whether the results analysing the mechanisms relating sugar cultivation to tenure systems are robust to different measures of sugar cultivation (log of days labour in 1862/63 and log of total production in 1892/95) in Table A5. All results hold.

D: Sugar suitability indices

Our sugar suitability index was computed using the bins and weights shown in Table A6. This results in a suitability value at the 3 arcsecond resolution which was then averaged at the district level. The weights are recalculated from Jayasinghe and Yoshida (2010). Jayasinghe and Yoshida (2010) included data on land use, evaporation, relative humidity, and a few additional variables, that had a total weight of 25 percent in their model. We excluded those but reweighted the included variables so that they retained their relative importance.

FAO data

The FAOs index on agro-climatic potential yield would be the most suitable indicator. However, as can be seen in Fig. A1, this indexshows hardly any variation across the island: except for a few mountain ranges, much of the island has the same value. Moreover according to this index, those areas we know to be sugar producing, the lowlands along the coast are less suitable than mountainous regions. An alternative would be using the FAOs agro-ecological attainable yield, or suitability index, for sugar. However, as noted above, these indices contain current data about population distribution, land use and farming techniques. Because the inputs for agro-climatic potential yields (including variables on temperature, extreme temperature events, rainfall, rainfall distribution, soil

Table A3
OLS estimation of relationship between sugar Labour and Production and Land Gini: Robustness Test. Sources: see text.

	Dependent variable: Land Gini among Landholders						Dependent variable: Land Gini among Population					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Log (Sugar Laborers 1862/63 + 1)	−0.742***	−0.696***	−0.465***				−0.405*	−0.422**	−0.231			
	(0.174)	(0.17)	(0.174)				(0.216)	(0.202)	(0.214)			
Log (Sugar Production 1892/95 + 1)				−0.954***	−0.765***	−0.683***				−0.358	−0.531**	−0.298
				(0.22)	(0.227)	(0.235)				(0.297)	(0.258)	(0.277)
Demogr. & distance controls	NO	YES	YES	NO	YES	YES	NO	YES	YES	NO	YES	YES
Geographic controls	NO	NO	YES	NO	NO	YES	NO	NO	YES	NO	NO	YES
Observations	368	368	368	368	368	368	368	368	368	368	368	368
Clusters	72	72	72	72	72	72	72	72	72	72	72	72
R-squared	0.076	0.103	0.171	0.107	0.147	0.19	0.014	0.223	0.268	0.01	0.227	0.269

Standard errors are in parentheses. Errors clustered at regency level.
*** $p < .01$, ** $p < .05$, * $p < .1$.

Table A4
OLS Estimation of relationship between sugar cultivation and land tenure: Robustness Test with different samples. Sources: see text.

	Dependent variable: % Communal Land				Dependent variable: % Rotating Land			
	Sugar Sample		Communal Sample		Sugar Sample		Communal Sample	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
% Sugar Land 1866/70	2.246***		1.374**		2.128***		1.686**	
	(0.591)		(0.678)		(0.826)		(0.835)	
% Sugar Land 1892/95		1.589***		1.041***		1.690**		1.361**
		(0.593)		(0.383)		(0.744)		(0.576)
Controls	YES	YES	YES	YES	YES	YES	YES	YES
Observations	102	102	252	252	102	102	252	252
Clusters	37	37	52	52	37	37	52	52
R-squared	0.565	0.573	0.314	0.324	0.292	0.310	0.320	0.337

Robust standard errors are in parentheses. Errors clustered at regency level.
***$p < .01$, ** $p < .05$, * $p < .1$.

Table A5
OLS estimation of relationship between sugar cultivation and land tenure: Robustness Test with different measures of sugar cultivation. Sources: see text.

	Dependent variable: % Communal Land				Dependent variable: % Rotating Land			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log (Sugar Laborers 1862/63 + 1)	3.055***	1.332**			2.128***	1.783***		
	(0.687)	(0.558)			(0.729)	(0.645)		
Log (Sugar Production 1892/95 + 1)			3.640***	1.561**			2.317***	1.812**
			(0.862)	(0.708)			(0.770)	(0.728)
Controls	NO	YES	NO	YES	NO	YES	NO	YES
Observations	368	368	368	368	368	368	368	368
Clusters	72	72	72	72	72	72	72	72
R-squared	0.093	0.400	0.112	0.402	0.092	0.329	0.092	0.323

Robust standard errors are in parentheses. Errors clustered at regency level.
*** $p < .01$, ** $p < .05$, * $p < .1$.

Table A6
Suitability bins sugar. Sources: Jayasinghe and Yoshida (2010) and Dippel et al. (2020).

	4	3	2	1	2	3	4	Weight
Temperature (°C)	<19	20–22	23–25	26–30	31–35	36–38	>38	29.3%
Rainfall (mm)	<750	750–1000	1000–1200	1200–1500	1500–2000	2000–2500	>2500	25.3%
Soil pH	<5	5–5.5	5.6–6	6.1–6.9	7–7.5	7.6–8.4	>8.5	12%
Slope (%)				<15	15–30	30–60	>60	10%
Texture				sandy clay loam/ clay loam	sandy loam / loam	loamy sand	clay/sand	8%
Elevation (m)			<0	0–500	500–1000		>1000	4%

moisture etc.) shows comparatively little variation across Java, the additional variables on land use, farming techniques, inputs, and management (and many more), that likely are quite different at present then around the year 1900. The large weight of the variable “inputs” can be observed by looking at the differences in the suitability maps for sugar with low (Fig A2) vs. high inputs (Fig. A3). Low inputs imply traditional agricultural techniques, is subsistence oriented using “labor-intensive techniques, no application of nutrients, no use of chemicals for pest and disease control and minimum conservation measures.” High inputs imply market-oriented “production is based on improved high yielding varieties, is fully mechanized with low labor intensity and uses optimum applications of nutrients and chemical pest, disease and weed control.” (Fischer et al. 2021: 54). The suitability of sugar cane cultivation across Java more or less reverses because of changing inputs. With high inputs, the mountains are the best place to start cultivating sugar, while lowland coastal areas, where sugar was cultivated for two centuries, are now unsuited for sugarcane cultivation. This puts doubts on the validity of these suitability indices for historical sugar cultivation. Finally, when comparing Figs. A1-A3 to Fig. 7 it also becomes clear that our own constructed index is made at a much larger resolution.

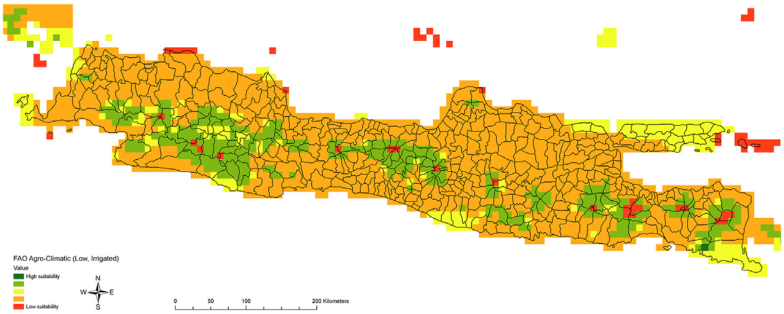

Fig. A1. Agro-Climatic Potential Yield for Sugar across Java.
Sources: FAO (2021).

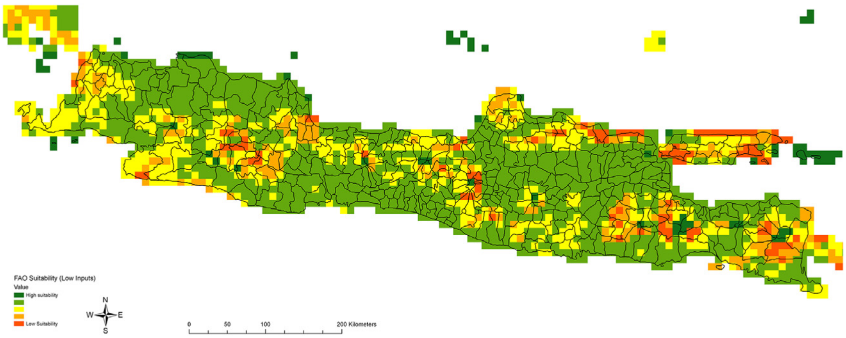

Fig. A2. Agro-Ecological Attainable Yield (Suitability) for Sugar across Java: Low Inputs.
Source: FAO 2021).

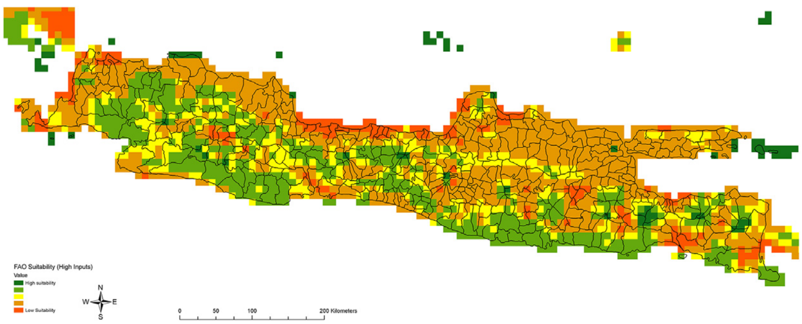

Fig. A3. Agro-Ecological Attainable Yield (Suitability) for Sugar across Java: High Inputs.
Source: FAO (2021). FAO (2021). Food and Agriculture Organization. *Global Agro-Ecological Zones*: https://gaez.fao.org/ Last visited 01–11–2021.

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