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Impact of large-scale, government legislated and funded organic farming training on pesticide use in Andhra Pradesh, India: a cross-sectional study

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Summary

Background The use of pesticides in agriculture has been associated with the destruction of biodiversity and damage to human health. A marked reduction in pesticide use is urgently required globally, but whether this can be achieved rapidly and at scale is unclear. We aimed to assess whether government-legislated and funded organic farming training in Andhra Pradesh, India, reduced pesticide use by farmers and sales of pesticides by pesticide retailers.

Methods We did a cross-sectional survey between Aug 11 and Nov 26, 2020, among farmers and pesticide retailers in Kurnool District of Andhra Pradesh (India). We assessed the impact of the Andhra Pradesh Community Managed Natural Farming (APCNF) programme, which aims to transition 100% of the agricultural land of Andhra Pradesh (population approximately 49 million, 6 million of whom are farmers) to organic farming practices by 2030. We did cross-sectional phone interview surveys of farmers and face-to-face surveys of pesticide retailers. We used multivariable Poisson regression models to estimate relative risks (RRs) and logistic regression models to estimate odds ratios (ORs).

Findings 962 farmers were invited to participate, of whom 894 (93%) consented (709 conventional farmers and 149 APCNF farmers). 47 pesticide retailers were invited to participate, of whom 38 (81%) consented. APCNF farmers had practised APCNF for a median of 2 years (IQR 1–3). APCNF farmers were less likely to use pesticides than conventional farmers (adjusted RR 0·65 [95% CI 0·57–0·75]), although pesticide use remained high among both APCNF and conventional farmers (73 [49%] of 148 APCNF farmers *vs* 695 [99%] of 700 conventional farmers; p<0·0001). APCNF farmers had lower pesticide expenditures than conventional farmers (median US$0 [IQR 0–170] for APCNF farmers *vs* $175 [91–281] for conventional farmers; p=0·0001). Increased frequency of meeting with agricultural extension workers was associated with reduced pesticide use among ACPNF farmers. Seven (18%) of 38 retailers reported a decrease in sales of pesticides in the past 4 years; no difference in the odds of reporting a decrease in pesticide sales in the past 4 years was identified between APCNF retailers and conventional retailers (OR 0·95 [95% CI 0·58–1·57]).

Interpretation Despite a major government drive for organic agriculture, about half of APCNF farmers continued to use pesticides and no impact on pesticide sales at local retailers was observed. A combination of policy instruments (eg, bans on highly hazardous pesticides), not solely training for farmers, might be needed to eliminate pesticide use in agriculture.

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For the Telugu translation of the abstract see Online for appendix 1

For the Hindi translation of the abstract see Online for appendix 2

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Introduction

The widespread use of synthetic pesticides in agriculture has been associated with a variety of environmental and human health harms.[1,2] Pesticide exposures among agricultural workers have been linked to DNA damage, oxidative stress, specific cancers, respiratory and thyroid effects, neurological disorders, chronic kidney disease, and type 2 diabetes.[1,2] Globally, an estimated 14 million suicides have been attributed to pesticide self-poisoning since the start of the green revolution.[3]

Despite these adverse effects on human and environmental health, few large scale government initiatives have targeted a reduction in pesticide use. Such strategies range from legal regulations such as bans of highly hazardous pesticides,[4,5] to knowledge transfer and technical support provided by government agricultural extension workers,[6] to wholesale shifts to organic agriculture.[7] Research on the impact of government policies to reduce pesticide use is also scarce and has largely been conducted in Europe in the past 25 years.[8] In India, 19 states have organic farming policies, schemes, or missions, including one state where the use of synthetic pesticides and fertiliser is completely banned,[9] but to date, no surveys have evaluated the impact of these government initiatives on pesticide use.[10]

Research in context

Evidence before this study

We searched Web of Science for studies published between Jan 13, 2016, and Jan 13, 2021, using the search terms "pesticide use" and "policy" in all fields, and reviewed studies done in low-income and middle-income countries (LMICs). One study was identified that evaluated the impact of an agroecological programme implemented at scale on pesticide use among farmers in LMICs. The One Must Do, Five Reductions programme has been implemented in rice production systems of two Vietnamese provinces; survey data collected in 2019 indicated that 74% of farmers had reduced their use of pesticides.

Added value of this study

This is the first study to evaluate the impact of a large scale government-funded organic agriculture programme on pesticide use across all crops. Our study provides three key additions to the evidence base. First, policies that support the training of farmers in organic agricultural practices have the potential to substantially reduce the use of pesticides, with important long-term effects on biodiversity and human and environmental health. This finding demonstrates that farmers are willing to switch from pesticide use when viable alternatives are available. Second, increased frequency of meeting with agricultural extension workers is an important predictor of reduced pesticide use; thus, increasing investment in the employment of agricultural extension workers to enable easier access to them for farmers when issues arise (eg, pest attacks) is crucial for policy effectiveness. Third, this policy approach is not strong enough to affect pesticide sales at local retailers, and ready availability of pesticides might hinder full adoption of organic practices.

Implications of all the available evidence

Well-designed state-led interventions that include a combination of policy instruments, targeting not only farmers but also retailers, are needed to reduce pesticide use in agriculture. In contexts where such interventions are underway, more research is required to understand the potential health benefits of observed reductions in pesticide use.

There are some early signs that the predominant agricultural framework favouring the use of synthetic chemicals is shifting. The Farm to Fork Strategy of the European Commission set a target of at least 25% of agricultural land in the European Union (EU) to be organically farmed by 2030;[11] at present, it is estimated that 7·5% of EU agricultural land is organically farmed.[12] In India, in the southern state of Andhra Pradesh, which has a population of approximately 49 million people, including 6 million farmers,[13] a target of 100% chemical-free agriculture by 2030 has been set. The policy—Andhra Pradesh Community Managed Natural Farming (APCNF; formerly known as zero budget natural farming)—was adopted in 2016 and calls for the provision of intensive farmer training by government agricultural extension workers known as community resource persons (panel).

For more on the **Andhra Pradesh Community Managed Natural Farming Initiative** see http://apzbnf.in/

The aim of this study was to determine whether the APCNF policy reduced the use of pesticides by farmers and sales of pesticides by pesticide retailers. This is the first study to assess the impact of a large scale government-funded agriculture programme on pesticide use for multiple crops. The findings will improve understanding of the effects of such policies, and could have global implications as the predominant agricultural framework shifts from the use of synthetic chemicals towards organic farming.

See Online for appendix 3

Methods

Study design and participants

The study was conducted in Kurnool District, one of 13 districts in the state of Andhra Pradesh (India; figure 1). 48% of the total land area in Kurnool District is cultivated and 31% of the cultivated land is irrigated.[14] Major crops (in order of area cultivated) include cotton, Bengal gram (chickpea), paddy (rice), groundnut, red gram, and Jowar (sorghum).[14] The net sown area has marginally decreased from 2016–17 to 2018–19, whereas chemical fertiliser and pesticide consumption has increased.[14–16] The number of suicides among farmers in Kurnool District is the highest of any district in the state of Andhra Pradesh: 307 farmers died by suicide between 2015 and 2019, representing 29% of all suicidal deaths among farmers in the state during that time period.[17] This district was selected on the basis of stakeholder consensus during a 2 day workshop held in Hyderabad, India, in February, 2020 before implementation of the study. The decision was partly based on the high rate of suicides among farmers in this district and the fact that the cropping pattern is similar to Andhra Pradesh as a whole. However, the farmers surveyed were more likely to own medium or large farms and to be male and literate than the overall district or state population (appendix 3 p 3).

We did cross-sectional surveys of farmers and pesticide retailers in Kurnool District between Aug 11 and Nov 26, 2020. The farmer surveys were conducted via phone interviews (due to COVID-19-related restrictions on face-to-face interviews at the time of the survey) by trained enumerators between Aug 11 and Oct 25, 2020. Eligible individuals were aged 18 years or older, could speak Telugu, were currently a practicing farmer (defined as responding yes to the question, ''Did you cultivate any crop last year [2019]?''), and provided verbal informed consent. Farmers were contacted from a list provided by four non-governmental organisations (NGOs) operating in Kurnool District to implement rural development programmes or the APCNF programme. All contacts were compiled into two Excel spreadsheets: one for conventional farmers and one for APCNF farmers. Conventional farmers were randomly selected from the list of 8287 farmers until at least 700 conventional farmers had been surveyed. All APCNF farmers on the list were contacted. The farmer survey (appendix 3 pp 11–18) took, on average, 32 min to complete.

Pesticide retailer surveys were conducted via face-to-face interviews by trained enumerators between Nov 23 and 30, 2020. We purposefully selected three local government areas (known as mandals) within Kurnool District on the basis of the results of the farmer survey: two mandals with high levels of synthetic pesticide use, as reported by farmers, and one mandal with a high proportion of farmers reportedly practicing APCNF. Within these three mandals, we surveyed all pesticide retailers in the mandal headquarters, which was accomplished by walking across all streets of the market area, listing all pesticide retailers, and enquiring with the owners regarding any retailers outside the market area. Following this mapping, trained enumerators asked all listed retailers if they were willing to participate, and if verbal informed consent was obtained, proceeded with administering the survey. The retailer survey (appendix 3 pp 19–21) took, on average, 15 min to complete.

The study protocol was reviewed and approved by the Harvard University Ethics Committee (IRB20-0207) and the Centre for Chronic Disease Control Ethics Committee (IRB00006330). All participants provided verbal informed consent.

Data collection

The farmer survey and pesticide retailer survey were developed during the 2 day workshop in February, 2020. Questions were similar to those asked in routine government surveys,[18,19] with minor adaptations made on the basis of the workshop and pilot testing.

All data were entered into electronic data capture software (Qualtrics). Demographic data included sex, age, and education. Agricultural production questions referred to 2019 and were collected by season (Kharif [monsoon; July–October] and Rabi [winter; October–March]) for commercial crops (ie, not including home gardens). Questions included which crops were cultivated, how much land was cultivated, how much of that land was irrigated, and how much of that land was owned. Land areas were reported in local units and converted into hectares. Four farm size categories were defined according to land ownership in Kharif: tenant (0 hectares); small or marginal (0·01–2·00 hectares); medium (2·01–4·00 hectares); and large (>4·00 hectares).[18] We asked farmers about their input use and expenditures, including fertilisers and pesticides. Expenditures were reported in Indian Rupees (INR) and converted to US$ based on the official exchange rate from the World Bank (local currency units per US$, period average;

Panel: The APCNF government policy in India

The Andhra Pradesh Community Managed Natural Farming (APCNF) policy promotes zero synthetic chemical inputs, and emphasises four farming practices: microbial seed coating with cow-dung-based and urine-based formulations; enhancing the soil microbiome by integrating cow dung and urine; cover cropping and mulching; which together result in greater soil humus (organic matter) and improved soil aeration and water retention. The programme also promotes the use of botanical extracts for pest management, minimal tillage using indigenous seeds, and crop diversity.

Rythu Sadhikara Samstha (RySS) was established by the government of Andhra Pradesh to train the 6 million farmers who reside in the state in APCNF practices. As of December 2020, RySS had trained 580 000 farmers across 3011 villages in the state. APCNF training is implemented by farmers known as community resource persons (CRPs). CRPs are selected via a community audit, in which natural farming knowledge and leadership skills are evaluated. After selection, CRPs are trained for 1 year before being placed in the field. Clusters of around 2000 farming households are assigned 2–5 CRPs, who are paid by the government to live in the cluster and motivate and support farmers in adopting APCNF practices. CRPs also identify a pool of master farmers, known as internal community resource persons (iCRPs), some of whom are trained for 2–3 years to become CRPs for new clusters. One iCRP is appointed for every 100 farmers.

NGOs are also involved. Implementing NGOs assist with farmer training at the cluster level. Resource NGOs contribute to the programme by providing expertise and evaluation support.

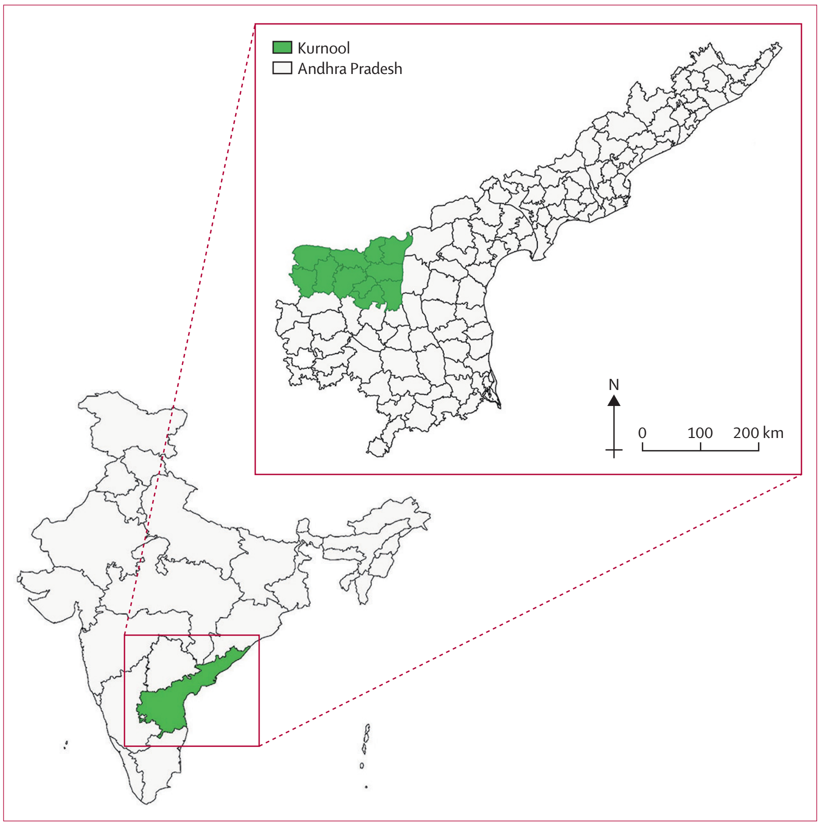

Figure 1: **Location of study in Kurnool District, Andhra Pradesh, India**

70·42 INR to $1).[20] For farmers who used synthetic fertilisers and pesticides, we asked about change in use over the past 4 years and reasons for any change. Reasons for changes in pesticide use were only analysed if reported by more than 5% of participants. For pesticides, we also asked how many different types of pesticides are used and what pesticides are used. To avoid report bias, all questions specific to APCNF were asked at the end of the survey. Questions included whether the respondent identified as an APCNF farmer, and, if yes, what season (kharif or rabi) they practised APCNF, for how many years, for commercial purposes or for home consumption, total land cultivated under APCNF, pest management on that APCNF land, training received relating to APCNF, and frequency of meeting with CRPs or internal CRPs (iCRPs) and NGOs.

For more on the **study analyses** see https://aspredicted.org

The pesticide retailer survey asked about retailer education, family agricultural practices, how long they have been in business, number of employees, hours and days of operation, products available, best selling products, method of selling products, changes in sales of fertiliser and pesticides in the past 4 years, and reasons for changes in sales. Reasons were only analysed if reported by more than 5% of retailers. We also asked about where information for recommendations made to farmers by retailers comes from, awareness of APCNF training in their area, opinions about APCNF, opinion regarding how APCNF will influence the amount and types of products sold, and opinion regarding how APCNF will influence their recommendations to farmers.

Statistical analysis

The prespecified primary outcome for the farmer surveys was self-reported use of synthetic pesticides (yes or no). The prespecified primary outcome for the retailer surveys was a self-reported decrease in pesticide sales over the past 4 years (yes or no). All analyses were conducted using Stata (version 16.0). We conducted a complete-case analysis. Data were missing for less than 15% of farmers for all covariates, with the exception of sex (appendix 3 p 4). A two-sided p value of less than 0·05 was considered to indicate a statistically significant difference. Study analyses were preregistered online. All analyses were conducted as specified, with the exception that responses for previous APCNF farmers and conventional farmers were combined due to the small sample size of farmers who previously practised APCNF but do not currently practice APCNF. We also did two exploratory analyses for the predictors of synthetic pesticide use among APCNF farmers and predictors of dropping out of the APCNF programme. Additionally, two changes were made to the preregistered analysis plan for the retailer survey. First, we only divided retailers according to retailer awareness of APCNF training in their area, not by mandals with high APCNF based on the farmer survey considering the small number of retailers per mandal surveyed. Second, we did not adjust the primary outcome models because the number of retailers with the outcome of interest (decrease in pesticide sales in the past 4 years) was small.

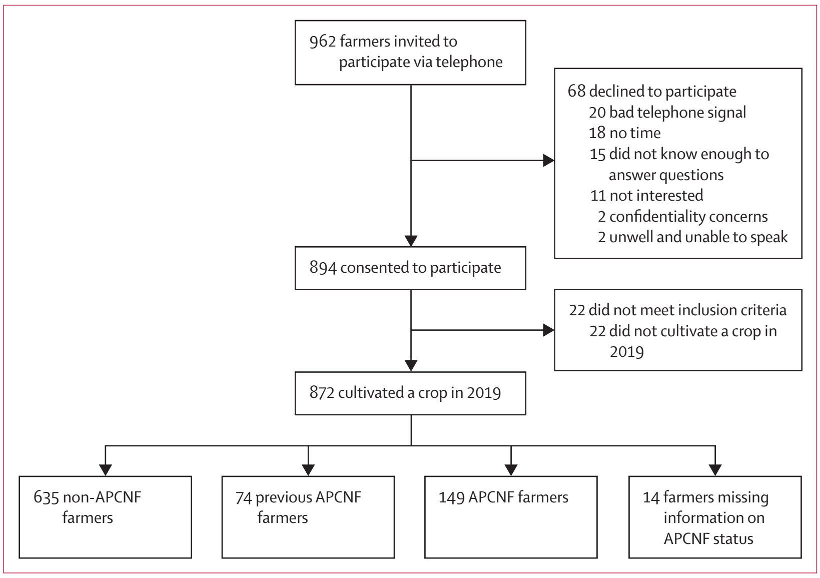

Figure 2: **Participant flow diagram**
APCNF=Andhra Pradesh Community Managed Natural Farming.

Shapiro-Wilk tests for normality indicated that all continuous variables were non-normal and thus we reported medians (IQR) and used non-parametric testing. Comparisons between conventional farmers and APCNF farmers were made using χ^2 tests for categorical variables and Kruskal-Wallis tests for continuous variables. For the primary outcome models, the independent variable was self-identifying as currently being an APCNF farmer (yes or no). The dependent variable was self-reported use of synthetic pesticides (yes or no). This outcome was common (>90%), therefore we modelled our data using Poisson regression models with robust SEs, which estimate relative risks (RRs) and 95% CIs.[21] Unadjusted and adjusted model estimates were presented for age, education, cultivating paddy (rice), farm size, irrigation, and synthetic fertiliser use.

For the exploratory analysis of predictors of synthetic pesticide use among APCNF farmers, predictors evaluated were: age, education, cultivating paddy (rice), farm size, irrigation, number of years practicing APCNF, practicing APCNF on all of their land (eg, exclusive APCNF farming), and frequency of meeting with CRPs or iCRPs or NGOs. For the exploratory analysis of predictors of previous APCNF, independent variables evaluated were: age, education, cultivating paddy (rice), farm size, irrigation, and synthetic fertiliser use. Both models were estimated using Poisson regression with robust SEs.[21]

Comparisons between conventional and APCNF retailers were made using χ^2 tests for categorical variables and Kruskal-Wallis tests for continuous variables. For the primary outcome models, the independent variable was retailer awareness of APCNF training in their area (yes or no). The dependent variable was a binary outcome: a decrease in pesticide sales over the past 4 years (yes or no).

	Total (n=872)*	Conventional farmers (n=709)	APCNF farmers (n=149)	p value†
Sex‡				
Female	55/551 (10%)	26/405 (6%)	28/135 (21%)	<0·0001
Male	496/551 (90%)	379/405 (94%)	107/135 (79%)	..
Age, years				
<30	154/871 (18%)	112/708 (16%)	38 (26%)	0·0031
30–39	261/871 (30%)	209/708 (30%)	49 (33%)	..
40–49	245/871 (28%)	201/708 (28%)	40 (27%)	..
≥50	211/871 (24%)	186/708 (26%)	22 (15%)	..
Education				
No formal school education	248/871 (28%)	218 (31%)	26/148 (18%)	0·0015
Primary	239/871 (27%)	199 (28%)	37/148 (25%)	..
Secondary	270/871 (31%)	208 (29%)	59/148 (40%)	..
Graduate, post-graduate, or professional degree	114/871 (13%)	84 (12%)	26/148 (18%)	..
Farm size				
Tenant (0 hectares)	52 (6%)	40 (6%)	10 (7%)	<0·0001
Small and marginal (0–2·00 hectares)	395 (45%)	287 (40%)	101 (68%)	..
Medium (2·01–4·00 hectares)	259 (30%)	236 (33%)	22 (15%)	..
Large (>4·00 hectares)	166 (9%)	146 (21%)	16 (11%)	..
Proportion of land cultivated in Kharif 2019 that was owned, %				
0	35/854 (4%)	24/692 (3%)	10 (7%)	0·17
1–99	238/854 (28%)	195/692 (28%)	38 (26%)	..
100	581/854 (68%)	473/692 (68%)	101 (68%)	..
Proportion of land cultivated in Kharif 2019 that was irrigated, %				
0	466/854 (55%)	421/692 (61%)	39 (26%)	<0·0001
1–99	159/854 (9%)	137/692 (20%)	19 (13%)	..
100	229/854 (27%)	134/692 (19%)	91 (61%)	..
Cultivated a crop in Kharif in 2019				
Yes	353 (99%)	696 (98%)	149 (100%)	0·096
No	13 (1%)	13 (2%)	0	..
Crops cultivated in Kharif in 2019‡				
Groundnut	265 (30%)	244 (34%)	18 (12%)	<0·0001
Cotton	232 (27%)	200 (28%)	29 (19%)	0·028
Paddy (rice)	176 (20%)	90 (13%)	80 (54%)	<0·0001
Bengal gram (chickpea)	127 (15%)	113 (16%)	10 (7%)	0·0035
Red gram	127 (15%)	109 (15%)	17 (11%)	0·21
Jowar (sorghum)	98 (11%)	90 (13%)	6 (4%)	0·0023
Millets	79 (9%)	74 (10%)	4 (3%)	0·0028
Cultivated a crop in Rabi in 2019				
Yes	286/869 (33%)	201/706 (28%)	81 (54%)	<0·0001
No	583/869 (67%)	505/706 (72%)	68 (46%)	..
Crops cultivated in Rabi in 2019‡				
Groundnut	70/869 (8%)	60/706 (8%)	10 (7%)	0·47
Paddy (rice)	50/869 (6%)	19/706 (3%)	29 (19%)	<0·0001
Bengal gram (chickpea)	44/869 (5%)	40/706 (6%)	4 (3%)	0·13
Vegetables	39/869 (4%)	32/706 (5%)	7 (5%)	0·93
Black gram	34/869 (4%)	20/706 (3%)	14 (9%)	0·0002

(Table 1 continues in next column)

(Continued from previous column)

Data are n (%). APCNF=Andhra Pradesh Community Managed Natural Farming. *Includes 14 farmers who were missing information on APCNF status. †p value from χ^2 test comparing conventional and current APCNF farmers. ‡Due to an error in Qualtrics electronic data capture, data on sex were missing for 321 (37%) of 872 respondents. ‡Farms could grow more than one crop, thus some percentages exceed 100.

Table 1: **Demographic and farm characteristics of farmers in Kurnool district of Andhra Pradesh (India) by APCNF status in 2019**

The ‘‘No’’ category included retailers who responded, ‘‘No change’’, ‘‘Increased’’, or ‘‘Not sure’’. Models were estimated using logistic regression.

Role of the funding source

The study funders had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

962 farmers were invited to participate, of whom 894 (93%) consented (figure 2). Of the 894 farmers, 149 currently identified as APCNF farmers, 74 had previously practised APCNF but were not currently practicing, 635 had never practised APCNF, and 14 were missing data on their APCNF status. The 74 farmers who had previously practised APCNF but were not currently practicing and the 635 farmers who had never practised were analysed together as conventional farmers (n=709). APCNF farmers were nearly twice as likely to cultivate in

	Total (n=872)*	Conventional farmers (n=709)	APCNF farmers (n=149)	p value†
Use synthetic fertilisers‡	734/869 (84%)	657/707 (93%)	65 (44%)	<0·0001
Expenditures on fertilisers, US$ per hectare	175 (88–351)	211 (105–351)	88 (30–246)	<0·0001
Change in fertiliser use in the past 4 years§				
Decreased	146/856 (17%)	101/698 (14%)	43/147 (29%)	<0·0001
Increased	398/856 (46%)	310/698 (44%)	81/147 (55%)	..
No change	294/856 (34%)	270/698 (39%)	22/147 (15%)	..
Other	18/856 (2%)	17/698 (2%)	1/147 (1%)	..
Use synthetic pesticides¶	778/858 (91%)	695/700 (99%)	73/148 (49%)	<0·0001
Expenditures on pesticides, US$ per hectare	155 (70–281)	175 (91–281)	0 (0–170)	<0·0001
Change in pesticide use in the past 4 years||				
Decreased	90/776 (12%)	64/692 (9%)	25/74 (34%)	<0·0001
Increased	482/776 (62%)	440/692 (64%)	37/74 (50%)	..
No change	189/776 (24%)	175/692 (25%)	11/74 (15%)	..
Other	15/776 (2%)	13/692 (2%)	1/74 (1%)	..
Number of different types of pesticides used**				
1	68/762 (9%)	58/685 (8%)	10/73 (14%)	0·0039
2	192/762 (25%)	178/685 (26%)	13/73 (18%)	..
3	205/762 (27%)	187/685 (27%)	16/73 (22%)	..
4	162/762 (21%)	152/685 (22%)	10/73 (14%)	..
5	82/762 (11%)	67/685 (10%)	14/73 (19%)	..
≥6	53/762 (7%)	43/685 (6%)	10/73 (14%)	..
Most commonly used pesticides				
Chlorantraniliprole	312 (36%)	288 (41%)	24 (16%)	<0·0001
Monocrotophos (organophosphate)	226 (26%)	207 (29%)	17 (11%)	<0·0001
Emamectin benzoate	176 (20%)	170 (24%)	6 (4%)	<0·0001
Pride insecticide (imidacloprid)	136 (16%)	125 (18%)	10 (7%)	0·0009
Sixer fungicide (mancozeb and carbendazim)	86 (10%)	86 (12%)	0	<0·0001
Dithane M45 fungicide (mancozeb)	50 (6%)	48 (7%)	2 (1%)	0·010
Store pesticides in the house††	60/766 (8%)	55/648 (8%)	5/118 (4%)	0·11

Data are n (%) or median (IQR). APCNF=Andhra Pradesh Community-managed Natural Farming. *Includes 14 farmers missing information on APCNF status. †p value from χ^2 test for categorical variables and Kruskal-Wallis test (a rank-based nonparametric test) for continuous variables comparing conventional and current APCNF farmers. ‡One of the 14 farmers with missing information on APCNF status was also missing data for this variable. §Three of the 14 farmers with missing information on APCNF status were also missing data for this variable. ¶Four of the 14 farmers with missing information on APCNF status were also missing data for this variable. ||Four of the 14 farmers with missing information on APCNF status were also missing data for this variable. **Ten of the 14 farmers with missing information on APCNF status were also missing data for this variable.††All 14 farmers with missing information on APCNF status were also missing data for this variable.

Table 2: **Input use among farmers in Kurnool district of Andhra Pradesh, India, according to APCNF status in 2019**

Rabi (54%) than conventional farmers (28%) and were more likely to cultivate paddy (rice) and less likely to cultivate other crops such as groundnut and cotton (all p<0·05; table 1).

The median age of farmers was 40 years (IQR 32–49) and the majority were male (496 [90%] of 551 farmers for whom data on sex were available; table 1). 248 (28%) of 871 farmers had no formal schooling and 395 (45%) of 872 were small or marginal farmers. APCNF farmers were more likely to be women, younger, small or marginal farmers, and have a higher educational attainment than conventional farmers (all p<0·05; table 1). APCNF farmers were also more likely to irrigate all of their cultivated land than conventional farmers (91 [61%] of 149 APCNF farmers *vs* 134 [19%] 692 conventional farmers; p<0·0001; table 1).

Of 149 APCNF farmers, 123 (83%) reported practicing APCNF for commercial purposes, nine (6%) for home consumption only, and 17 (11%) for both home consumption and commercial purposes. APCNF farmers had practised APCNF for a median of 2 years (IQR 1–3) on 50% (27–100) of their cultivated land. 43 (29%) of 149 APCNF farmers were exclusively practicing APCNF (eg, practicing APCNF on all of their land). APCNF training was received primarily from NGOs (83 [56%] of 149 APCNF farmers), followed by the internet (12 [8%]), Palekar workshops (ten [7%]), from fellow farmers (ten [7%]), and family (eight [5%]). 54 (36%) of 148 APCNF farmers reported interacting with CRPs or iCRPs more than once a week, 49 (33%) once a week, 14 (9%) 1–3 times per month, nine (6%) only when there was a problem, and 22 (15%) reported never interacting with CRPs or iCRPs. 23 (15%) of 149 ACPNF farmers reported interacting with NGOs more than once a week, 58 (39%) reported once per week, 25 (17%) 1–3 times per month, nine (6%) only when there was a problem, and 34 (23%) reported never interacting with NGOs.

APCNF farmers were significantly less likely to report using synthetic pesticides than conventional farmers, although use remained common among APCNF farmers (73 [49%] of 148 APCNF farmers *vs* 695 [99%] of 700 conventional farmers; p<0·0001; table 2). Overall, 226 (26%) of 872 farmers reported using monocrotophos (WHO class 1b [highly hazardous] organophosphorus insecticide), 136 (16%) reported using imidacloprid, and 176 (20%) reported using emamectin benzoate (both WHO class 2 [moderately hazardous] insecticides).[22] The remaining commonly reported pesticides were classified as unlikely to present acute hazard in normal use, including chlorantraniliprole, which was reported by 312 (36%) of 872 farmers. Consistent with reported synthetic pesticide use, APCNF farmers had significantly lower median expenditures on pesticides per hectare compared with conventional farmers ($0 [0–170] among APCNF farmers *vs* $175 [91–281] among conventional farmers; p<0·0001; table 2).

Consistent with these findings, APCNF farmers were more likely to report a decrease in pesticide use over the past 4 years than conventional farmers (25 [34%] of 74 APCNF farmers *vs* 64 [9%] of 692 conventional farmers; p<0·0001) and less likely to report an increase in pesticide use than conventional farmers (37 [50%] *vs* 440 [64%]; p<0·0001; table 2). Conventional farmers were more likely to report weather-related reasons for a decrease in pesticide use than APCNF farmers (15 [23%] of 64 conventional farmers *vs* one [4%] of 24 APCNF farmers; p=0·037) whereas APCNF farmers were more likely to report APCNF training than conventional farmers (four [17%] of 24 APCNF farmers *vs* two [3%] of 64 conventional farmers; p=0·025; appendix 3 p 5). Conventional farmers were more likely to report pests as a reason for increases in pesticide use than APCNF farmers (370 [85%] of 437 conventional farmers *vs* 25 [68%] of 37 APCNF farmers; p=0·0074) and declining yield (165 [38%] of 437 conventional farmers *vs* six [16%] of 37 APCNF farmers; p=0·0088; appendix 3 p 5).

Models of synthetic pesticide use among APCNF farmers versus conventional farmers estimated an unadjusted RR of 0·50 (95% CI 0·42–0·59). Findings were robust to adjustment for confounders (adjusted RR 0·65 [95% CI 0·57–0·75]). When only farmers practicing APCNF on all of their land were considered, the unadjusted RR was 0·32 (0·20-0·51) and the adjusted RR was 0·48 (0·32–0·71); representing a 52% reduction in synthetic pesticide among exclusive APCNF farmers.

The exploratory analysis of predictors of synthetic pesticide use among APCNF farmers showed that farmers who practised APCNF exclusively were significantly less likely to use synthetic pesticides than those who did not practice APCNF exclusively (p=0·0017) and APCNF farmers who met with CRPs or iCRPs or NGOs once per week (p=0·0001) or more than once per week (p=0·0048) were significantly less likely to use synthetic pesticides than those who never met with CRPs or iCRPs or who met with them only 1–3 times per month (appendix 3 p 6). Farmers of large farms were significantly more likely to drop out of APCNF than farmers of small and marginal farms (p=0·030), and farmers who used synthetic fertilisers were significantly more likely to drop out of APCNF than those who did not use synthetic fertilisers (p<0·0001; appendix 3 p 7).

47 pesticide retailers were invited to participate, of whom 38 (81%) consented. Of the nine retailers who did not participate, six (67%) were closed at the time of the survey and three (33%) refused. Most retailers were open 7 days a week (82%) and all were open for at least 12 h per day (appendix 3 pp 8–9). All retailers surveyed sold insecticides, which were the most common products available. Organophosphorus insecticides were the most common type of insecticide sold, and, similar to the farmer survey, emamectin benzoate was reported as a top-seller in retail shops. Biopesticides were available in 13 (34%) of 38 shops, but mechanical pest management tools, such as sticky traps or pheromone traps, were only available in five (13%) shops. No significant differences in retailer characteristics were identified between retailers who were aware of APCNF training in their area and those who were not aware of such local training (all p>0·05; appendix 3 pp 8–9).

Seven (18%) of 38 retailers reported a decrease in sales of pesticides in the past 4 years (table 3). No significant differences were identified in the odds of reporting a decrease in pesticide sales in the past 4 years between APCNF retailers and conventional retailers (unadjusted odds ratio 0·95 [95% CI 0·58–1·57]). APCNF retailers were more likely to report weather as the reason for a change in sales than were conventional retailers (p=0·011), whereas conventional retailers were more likely to report changes in farmer demand (p=0·056).

	Total (n=38)	Conventional farmers (n=12)	APCNF farmers (n=26)	p value*
Change in fertiliser sales in the past 4 years				
No change	16 (42%)	5 (42%)	11 (42%)	0·48
Increased	15 (39%)	6 (50%)	9 (35%)	..
Decreased	7 (18%)	1 (8%)	6 (23%)	..
Reason for change in fertiliser sales				
Farmer demand	11 (50%)	6 (86%)	5 (33%)	0·022
Weather	6 (27%)	0	6 (40%)	0·050
Change in pesticide sales in the past 4 years				
No change	13 (34%)	3 (25%)	10 (38%)	0·63
Increased	18 (47%)	7 (58%)	11 (42%)	..
Decreased	7 (18%)	2 (17%)	5 (19%)	..
Reason for change in pesticide sales				
Farmer demand	9 (43%)	6 (67%)	3 (25%)	0·056
Weather	9 (43%)	1 (11%)	8 (67%)	0·011
Source of information for recommendations				
State agriculture department	10 (26%)	4 (33%)	6 (23%)	0·50
Manufacturer or supplier	13 (34%)	8 (67%)	5 (19%)	0·0042
Personal experience	12 (32%)	1 (8%)	11 (42%)	0·036
Opinion of APCNF				
Good for health of farmers	13 (38%)	2 (25%)	11 (42%)	0·38
Will lower crop yields	11 (32%)	2 (25%)	9 (35%)	0·61
Farmers will not adopt it	14 (41%)	4 (50%)	10 (38%)	0·56
Agree that APCNF will impact amount of products sold	9 (24%)	1 (8%)	8 (31%)	0·13
Agree that APCNF will impact types of products sold	4 (11%)	0	4 (16%)	0·16
Agree that APCNF will impact recommendations to farmers	5 (14%)	0	5 (19%)	0·14

Data are n (%). APCNF=Andhra Pradesh Community-managed Natural Farming. *p value from χ^2 test comparing areas with APCNF training and no APCNF training (conventional).

Table 3: **Sales, recommendations to farmers, and impact of APCNF as reported by pesticide retailers in three Mandals of Kurnool district of Andhra Pradesh (n=38)**

Discussion

After decades of promoting synthetic pesticides for food security, several governments around the world, the EU, and the UN Food and Agriculture Organization are promoting alternative approaches to pest management due to concerns regarding the health and environmental impacts of toxic chemicals. However, it is unclear whether it is possible to effectively and rapidly switch to organic farming at scale. We therefore evaluated a large-scale organic agriculture policy in a state in southern India that has set a target of 100% chemical-free farming by 2030 to determine its effects on agricultural pesticide use. Analysing the effectiveness of this substantial change in agriculture is important to understand what can be done rapidly at scale. We found that self-identified APCNF farmers were around a third less likely to use synthetic pesticides, had significantly lower expenditures on pesticides, and were more likely to report a decline in synthetic pesticides in the past 4 years than conventional farmers. These findings are especially encouraging considering the median time farmers in our sample had been practicing APCNF techniques was relatively short (2 years [IQR 1–3]).

Despite these promising findings, 49% of APCNF farmers used pesticides. However, pesticide use would not be expected to decrease to zero in the first couple of years following implementation of the programme. Zero-input and low-input practices are knowledge intensive and it can take time for farmers to gain confidence in them and become proficient. These practices also take time to become effective. If a farmer is using a broad-spectrum insecticide such as monocrotophos (which one in four farmers in our sample reported using) in one part of their farm, the insecticide will kill beneficial populations and reduce the effectiveness of APCNF across the whole farm. Similarly, APCNF farmers who are surrounded by conventional farmers will struggle to manage pests. This might partly explain why a large proportion of APCNF farmers who reported using pesticides actually reported an increase in use in the past 4 years, although this was a significantly smaller proportion than the conventional farmers who reported an increase in use.

An increase in pests was the most commonly reported reason reported by conventional and APCNF farmers for an increase in pesticide use in the past 4 years. Weekly data on pest outbreaks from the Andhra Pradesh Agriculture Commissioner showed no clear pattern for Kurnool District between 2016 and 2020 (appendix 3 p 10). No pest outbreaks were reported in Kurnool District in 2016. In 2018, outbreaks were reported for all major crops in the district; however, nearly all were classified as trace—ie, they affected less than 5% of cultivated land area. Furthermore, in 2019, very few pest outbreaks were reported. In our sample, farmers who cultivated groundnut in 2019 were more likely to report that their pesticide use increased due to pests compared with those who did not grow groundnut, which is consistent with Agriculture Commissioner data from 2019 that showed outbreaks of semi-looper, *Helicoverpa*, root rot, leaf folder, and sucking pests in groundnut crops in Kurnool District.

Understanding the motivators for adopting APCNF, which is a voluntary government-funded programme, could inform strategies for improving adherence to the APCNF package of practices and extending the reach of the programme. In our sample, impact on personal health was the most common reason reported by APCNF farmers for decreasing their pesticide use in the past 4 years. To date, empirical studies of the motivations for adopting APCNF have not been completed. One study conducted with six self-help groups for women across three districts of Andhra Pradesh (Anantapur, Guntur, and Visakhapatnam) established a preliminary method for such investigations, but did not draw conclusions regarding the underlying motivations.[23] Two previous studies including one in Telangana (previously part of Andhra Pradesh) have explored motivators for adopting organic farming more broadly.[24,25] Both studies found that contact with extension workers and institutional support were the strongest predictors of adopting organic farming practices, consistent with our study.[26,27]

There are several other examples of large-scale policies in Asia aimed at reducing pesticide use. In the smaller state of Sikkim in India (population of about 600 000 people[13]), the use of synthetic pesticides and fertilisers was banned completely in 2014. The sale and use of these products is punishable by law with imprisonment of up to 3 months, a fine of up to 100 000 INR (approximately $1365), or both.[26] A survey of 14 farmers conducted in 2016 suggested that farmers have not received adequate training to effectively treat pests or input support (eg, biopesticides) from the Indian Government.[26] To the best of our knowledge, no other surveys have evaluated the impact of the policy on pesticide use in Sikkim. An evaluation of the national One Must Do, Five Reductions programme in Vietnam conducted in July 2019 found that 346 (74%) of 465 rice farmers surveyed in two provinces had reduced their pesticide use.[27] This is a much larger decrease than observed in our study (34% of APCNF farmers had decreased their pesticide use). More research is needed to monitor the impacts of policies aimed at reducing pesticide use on farmer-reported use of pesticides.

Considering that only around a third of APCNF farmers reported a decrease in pesticide use, and the majority of farmers in the overall sample reported an increase in pesticide use in the past 4 years, the fact that retailers had not observed a decrease in sales is not unexpected. The APCNF programme does not currently involve pesticide retailers, although we did find qualitative evidence that APCNF retailers were more likely to report that APCNF is good for the health of farmers and less likely to report that farmers will not adopt APCNF practices. Considering that all retailers surveyed said that they advise farmers on the use of pesticides, this represents a missed opportunity to strengthen the implementation of the APCNF programme. A study in China found that government inspection, years in business, and information from government agricultural extension institutions were positively associated with the likelihood of retailers recommending the correct use of pesticides, whereas participation in training organised by pesticide companies reduced the likelihood of retailers recommending the correct use of pesticides.[28] Thus, government agricultural extension workers might prove to be valuable not only for the training of farmers, but also for the training of pesticide retailers.

Our study shows that APCNF training does have the potential to significantly reduce pesticide use. However, the current programme could be strengthened in several ways. A shift in production practices towards pesticide-free cultivation requires investment in farmer knowledge and this is reflected in our finding that interaction with extension workers was a strong predictor of reduced pesticide use. Training of more extension staff from the state department of agriculture in Andhra Pradesh and RySS (the government body responsible for implementation of APCNF) would enable a greater level of farmer support. In the context of the COVID-19 pandemic, farmers are increasingly reliant on online platforms for information. In our study, 8% of APCNF farmers reported learning about the programme via the internet. RySS is currently building content for an online platform, which could complement training at the field level. The APCNF programme does not explicitly involve pesticide retailers, which represents a missed opportunity to inform these important stakeholders about APCNF and increase access to tools needed for natural farming practices such as biocides and mechanical pest management tools, which were only available from 34% and 13% of retailers in our study, respectively.

The results of this study should be interpreted in the context of several limitations. We only sampled farmers and retailers from one of 13 districts in Andhra Pradesh. However, the district is representative of cropping patterns in the state, and considering the challenging agroecological conditions in the district, our findings are likely to be conservative relative to what would have been observed at the state level. We were not able to randomly sample respondents due to COVID-19-related restrictions on face-to-face interviews at the time the farmer surveys were conducted. We instead obtained a list of farmers from NGOs operating in Kurnool District. We cannot guarantee that either the conventional or APCNF farmers in our sample are representative of all conventional and APCNF farmers in Andhra Pradesh. However, we had a high response rate to phone interviews (>90%), partly due to the fact that enumerators were purposefully selected from conventional agricultural households in the district and thus were familiar with the local context. This high response rate reduced some selection bias. Our sample was more likely to be male, farmers of medium or large farms, and had a higher level of education than the overall population of Kurnool District and Andhra Pradesh, and these differences should be considered when generalising findings. Once in-person activities can safely resume, future research should aim to target groups underrepresented in our sample, particularly women, farmers with low levels of literacy, and farmers with small and marginal farms. Another limitation of the study was the use of self-reported synthetic pesticide use. We did not collect information on the amount of pesticide used or application frequency because we did not think this would be accurately reported via phone surveys. We tried to capture application rates by instead asking farmers to look at their receipts and report total expenditures, which we analysed on a per hectare basis. We also did not ask farmers to recall the specific types of pesticides used in the past and so we could not evaluate changes in the profile of pest management products (eg, if APCNF farmers are shifting to less toxic pesticides). Future research that prospectively monitors farmers as they transition from conventional to APCNF will help address this gap.

Key strengths of the study include the large sample size, the adjustment for multiple potential confounding factors in the farmer survey model, the measurement of pesticide use at the farm level, and the timely collection of data. The routine government Input Survey of pesticide use could not be used to evaluate the programme to date considering that the latest round was conducted in 2016–17, coincident with the year APCNF was adopted, and only aggregate district estimates are available (ie, no microdata).[29]

For more on the **routine government Input Survey** see https://inputsurvey.dacnet.nic.in/

In conclusion, findings from a median of 2 years after adoption of APCNF indicate that the programme has substantially reduced the use of pesticides in Kurnool District of Andhra Pradesh. Farmers have been willing to adopt the techniques, demonstrating that farmers are willing to switch from pesticide use when offered a viable alternative. These findings are encouraging because they show that a reduction in pesticide use at the farm level is possible on a large scale, in a short timeframe. However, 49% of APCNF farmers used some form of pesticide and demand has not yet changed enough for an impact to be observed on pesticide access at retailers. We found that training is crucial. A clear association was observed between increased frequency of meeting with extension workers and reduction in pesticide use. Access to agricultural extension workers for support in dealing with pests is especially important in a context where pesticides remain widely available, since farmers are likely to default to what they are familiar with, especially if they are unfamiliar with agroecological approaches. Thus, our findings suggest that government-led training programmes have the potential to reduce pesticide use, but that a combination of policy instruments, which might include private sector regulations (eg, bans on highly hazardous pesticides such as monocrotophos), not just farmer training, is likely to be needed for reductions to be observed on the scale envisioned by the Government of Andhra Pradesh (eg, complete elimination of pesticides). The proposed ban on 27 hazardous pesticides in India would be one such instrument.[30] Continued monitoring of pesticide use, especially personal exposure and resulting health effects, among farmers in Andhra Pradesh is needed to confirm findings and increase understanding with regard to the impact of this unique sustainable farming policy.

Contributors
LMJ, ME, SM, AR, PP, BS, AG-H, DV, NSV, RS, and SD conceptualised the study. ME and LMJ acquired study funding. RS and NSV oversaw data collection with support from LMJ. LMJ and SD cleaned the data. LMJ and SD had full access to and verified the underlying data. LMJ analysed the data. LMJ wrote the original draft of the paper and RS, SD, ME, SM, AR, PP, BS, AG-H, DV, and NSV reviewed and edited the paper. All authors read the final version and approved it before submission.

Declaration of interests
We declare no competing interests.

Data sharing
Deidentified participant data and a data dictionary will be available on publication in the Harvard Dataverse. Study analyses of the farmer survey and pesticide retailer survey were preregistered online.

For **deidentified participant data and a data dictionary** see https://doi.org/10.7910/DVN/SKU5BQ

For more on the **farmer survey** see https://aspredicted.org/gp4k7.pdf

For more on the **pesticide retailer survey** see https://aspredicted.org/22q8x.pdf

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