

Article

Bundling Fertilizer-Reduction Practices into Agri-Environmental Payment Design: A Choice Experiment with Rice Farmers' Preferences

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Abstract

Calibrating compensation programs for chemical-fertilizer reduction requires reliable evidence on farmers' preferences across reduction practices and policy instruments. Existing choice-experiment evidence treats reduction as either a single aggregate attribute or mutually exclusive practices, specifies compensation independently of the practice bundle, and underuses the distinction between smallholders and new agricultural operating entities (NAOEs) in heterogeneity analysis. We surveyed 1066 rice farmers across six counties and districts of Jiangsu Province using a multi-binary-attribute choice experiment that represented five fertilizer-reduction measures (soil-testing-based fertilization, deep placement, organic substitution, crop rotation, and straw return) as separate binary attributes, with a cost-proportional compensation rate; estimation used mixed logit. Non-monetary preferences vary qualitatively across measures: soil-testing-based fertilization is intrinsically valued (willingness to pay 24 CNY/mu), while crop rotation imposes the largest non-monetary cost (willingness to accept 152 CNY/mu). Existing Jiangsu flat rates approximate farmer mobilization thresholds for low- and medium-cost practices but under-incentivize rotation. Income subsidies dominate non-income alternatives. Smallholders are more inertial and more compensation-responsive than NAOEs, requiring more compensation for crop rotation and showing a stronger income-subsidy preference. The findings support differentiated compensation by measure and farmer type; the methodological template extends to other agri-environmental contexts in which adoption is genuinely combinatorial.

Keywords: choice experiment; mixed logit; willingness to accept; fertilizer reduction; agri-environmental compensation; preference heterogeneity

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1. Introduction

Excessive use of chemical fertilizer is among the most acute environmental challenges facing modern agriculture. Global inorganic-fertilizer consumption rose from 142 million tonnes in 2002 to 190 million tonnes in 2023 [1], with surplus nutrients accelerating soil acidification, eutrophication, and greenhouse gas emissions despite the yield gains they have supported [2,3]. These costs are particularly concentrated in China, where total

fertilizer use rose from 12.7 to roughly 50 million tonnes over four decades, with per-hectare application rates two to four times those of other major agricultural regions [4]. Within this context, rice production, which is China's largest cereal sector and a leading contributor to non-point-source nitrogen and phosphorus loss, has been a focal target for reduction [5]. Subregion-specific assessments based on extensive on-farm data indicate that nitrogen inputs in major Chinese rice systems can be reduced by 10–27% while still meeting national production targets [6], yet on-farm adoption of fertilizer-reduction practices has remained uneven [7]. Because this gap between agronomic feasibility of fertilizer reduction and actual adoption persists, the policy literature increasingly frames the challenge as one of incentive design: voluntary adoption is limited by the private costs that these practices impose on farmers, so compensation is required to make adoption individually worthwhile. Although compensation schemes have been widely advocated, empirical evidence on farmers' preferences over which specific practices should be compensated, and over the form that compensation should take, remains limited. The present study addresses this gap by estimating these preferences directly.

Stated-preference methods are survey-based techniques that infer preferences from respondents' choices among hypothetical alternatives. A choice experiment (CE) is a stated-preference method in which respondents repeatedly choose among alternatives described by systematically varied attributes, allowing the trade-offs and implicit monetary values underlying their choices to be inferred. Grounded in Lancaster's [8] characteristics theory of value and the random utility framework [9–12], these methods have become the standard tools for generating evidence on farmers' preferences in agri-environmental settings, and the literature relevant to fertilizer-reduction compensation design has advanced along three fronts. First, in the practices examined, existing CE studies have evaluated a range of fertilizer-reduction-related measures, considered either individually or as mutually exclusive levels of a single attribute. Examples include aggregate fertilizer-quantity reduction in lake-basin rice systems [13], organic substitution and bio-based replacement of chemical fertilizer [14,15], site-specific and precision nitrogen fertilization [16,17], and cover-crop intercropping and crop rotation [18]. Second, in the attributes employed, existing CE studies have examined a range of program-design attributes alongside reduction practices and payment level. These include the form, level, and delivery vehicle of compensation (flat-rate cash payments, cost-share rates, and in-kind transfers), technical support provisions [14], contract duration, exit and flexibility options, monitoring intensity, prescription-style restrictions on management practices, and regulatory concessions on existing nutrient-accounting requirements [19–23]. Third, in heterogeneity analyses of fertilizer-reduction and adjacent agri-environmental CEs, preference variation has been examined along two broad groups of respondent characteristics. The first comprises social and farm-characteristic variables, including respondent age, gender, education, household labor, farming experience, farm size or cultivated area, household income, and the share of household income from agriculture [19–21,23]. The second comprises psychological and behavioral variables, including risk preferences, environmental attitudes, technology affinity, and information-acquisition capacity [7,16].

Despite this progress, three gaps in the literature constrain its relevance for designing fertilizer-reduction compensation in the Chinese setting. First, the existing CE evidence overwhelmingly treats fertilizer-reduction measures, whether one at a time or as mutually exclusive alternatives [21,24,25], whereas farmers in practice adopt multiple measures jointly within their cropping systems. Therefore, recovering cross-practice willingness-to-accept (WTA, the compensation a respondent would require to adopt a practice) comparisons for differentiated budget allocation requires practice-specific estimates expressed on a common, internally comparable scale. Second, even as the broader (non-monetary) attribute set has diversified, the monetary attribute itself is almost universally specified as

fixed amounts that vary independently of the practice bundle in each alternative. This leaves the link between compensation and adoption cost unspecified, identifies the marginal utility of money against an unanchored scale, and limits the transferability of WTA estimates to programs in which subsidies are actually calibrated to implementation cost. Existing Jiangsu and ministry-level flat rates are already calibrated to cost in this way, however imperfectly. Third, heterogeneity analyses remain dominated by individual demographics, with the structural distinction between smallholder households and new agricultural operating entities (NAOEs) seldom used for subsample comparisons. Yet the two operator types (smallholders and NAOEs) may differ in both the motivations driving fertilizer reduction and the barriers constraining it. We therefore hypothesize that smallholders, facing tighter liquidity and behavioral barriers such as risk aversion and present-focused time preferences [26], are more compensation-sensitive but more inertial, whereas new agricultural operating entities (NAOEs), operating at larger scales with greater access to extension, credit, and equipment [4,7], absorb practice-change costs more easily and may face commercial pressures such as output-market certification, a conjecture the subsample analysis is designed to test. This distinction is analytically rather than merely descriptively important: because compensation is delivered through uniform per-mu rates, any systematic difference in compensation sensitivity between the two types implies cross-subsidization and a participation premium that demographic heterogeneity analysis cannot reveal, and it is directly policy-actionable, since Chinese agricultural support increasingly differentiates the two.

To address the three gaps identified above, we administered a CE to 1066 rice farmers across six counties and districts of Jiangsu Province with three corresponding design choices. To recover practice-specific, internally comparable WTA estimates, we represent each of five fertilizer-reduction measures (soil-testing-based fertilization, deep placement, organic substitution, crop rotation, and straw return) as a separate binary attribute (adopt/do not adopt), so that any policy alternative can combine any subset of the five and the combinatorial structure of farmer adoption decisions is preserved. These five are the reduction pathways promoted under China's fertilizer-reduction action plans and Jiangsu's rice-system programs, so the recovered estimates map onto deployable policy instruments. The monetary scale is anchored to implementation cost: the compensation attribute is cost-proportional, framed as a share of the alternative-specific incremental adoption cost (0%, 30%, 50%, 80%, or 100%), with per-measure costs disclosed to respondents prior to the choice tasks. The resulting compensation amount is bundle-specific, and the marginal utility of compensation is identified against a cost-anchored scale rather than an arbitrary one. Structural heterogeneity along the farm-operation dimension is captured through subsample analysis: we estimate the model on the full sample using mixed logit and re-estimate it separately on smallholder ($n = 481$) and NAOE ($n = 585$) subsamples, yielding subsample-specific WTA estimates for the five measures and the two non-income subsidy modes, the level at which the comparison between smallholders and NAOEs is most directly informative for differentiated policy design.

Two principal contributions follow from this design. Methodologically, the multi-binary-attribute design and the cost-proportional compensation framing together provide a CE template that yields practice-specific, monetary-scale WTA estimates suitable for the calibration of differentiated payment programs. The template is transferable beyond the Chinese fertilizer setting to other agri-environmental contexts in which adoption is genuinely combinatorial. Empirically, the WTA estimates reveal a heterogeneous preference structure across measures: soil-testing-based fertilization is intrinsically valued (a negative WTA), deep placement is approximately neutral, and crop rotation requires substantial inducement (152 CNY/mu). These estimates align closely with existing Jiangsu flat-rate subsidies for low- and medium-cost practices, but indicate that crop rotation is mate-

rially under-incentivized at currently available payment levels. The comparison between smallholders and NAOEs further documents systematic differences in compensation sensitivity, status-quo preference, and subsidy-form preference, indicating that uniform per-mu rates impose a non-trivial premium on smallholder participants. Together these findings provide direct, quantified inputs for the next iteration of fertilizer-reduction subsidy design.

The remainder of the paper is organized as follows. Section 2 describes the study area, the choice-experiment design, and the econometric framework. Section 3 presents the mixed-logit estimates, the WTA results, and the subsample comparisons. Section 4 discusses the findings and their implications for compensation-program design. Section 5 concludes.

2. Materials and Methods

2.1. Study Area and Sampling Design

We focus on Jiangsu Province, located on the eastern coast of China, as the study area. Jiangsu is one of the country's leading rice-producing regions, with provincial statistics recording approximately 20.0 million tonnes of rice output in 2023, and a priority area for fertilizer reduction under both the national Chemical Fertilizer Reduction Action Plan to 2025 and the provincial 14th Five-Year Plan for Cultivated Land Quality Construction. The province exhibits substantial intraregional variation along a north–south gradient: southern Jiangsu is economically more developed and characterized by larger-scale rice operations; central Jiangsu occupies an intermediate position; and northern Jiangsu features lower per-capita income and more pronounced soil-related challenges. Nanjing, the provincial capital, serves as the political and economic center and is typically among the earliest beneficiaries of agricultural-policy diffusion.

The sampling design followed a stratified, multistage procedure. Rice-cultivating households were first stratified along the standard provincial north–south classification into three subregions (southern, central, and northern Jiangsu), reflecting well-documented variation in cultivation conditions, operating scale, and economic development across Jiangsu's rice belt. Rice cultivation in Jiangsu is most extensively distributed across the southern and central subregions; in northern Jiangsu, large-scale rice production is concentrated in the eastern coastal areas, while the inland northwest is predominantly devoted to wheat-corn cropping systems. Within each stratum, counties were selected based on the joint criteria of typical subregional rice-production conditions and total rice-cultivation area: Zhangjiagang and Changshu in southern Jiangsu, Rugao in central Jiangsu, and Sheyang in northern Jiangsu (a major rice-producing county within coastal Yancheng). The Nanjing districts of Liuhe and Pukou were additionally included as representative rice-cultivation districts within the provincial-capital periphery, complementing the Suzhou pair to span the western and eastern ends of the southern Jiangsu rice belt. The selected counties together lie within a spatially bounded portion of Jiangsu's rice belt, preserving homogeneity in input prices, mechanization access, and labor costs, conditions under which the cost-proportional compensation framing developed in Section 2.2 applies uniformly across respondents. Within each selected county or district, townships, administrative villages, and households were then sampled in three successive stages. First, the townships with the largest rice-cultivation area were selected, typically five to eight per county. Second, within each selected township, at least three administrative villages were drawn at random using a random-number-table method. Third, within each selected village, rice-cultivating households were surveyed: the target number per village was set by subregion to reflect the prevailing operating scale (5–10 households in southern Jiangsu, 12–15 in central Jiangsu, and 15–20 in northern Jiangsu, where holdings are progressively smaller), and the sampled households were selected to include both smallholder house-

holds and NAOEs, with the proportion of each operator type controlled so that NAOEs, far less numerous than smallholders in the population, were sufficiently represented for the operator-type analysis. Face-to-face interviews were conducted by trained enumerators (graduate students with prior field-survey experience and project-specific training) at village-committee offices. Given the substantial information density of the questionnaire and the limited formal schooling of many respondents, enumerators read the introduction, attribute definitions, and the cost-information block aloud and verified comprehension before administering the choice tasks.

The survey was conducted from October 2024 through March 2025. A total of 1107 questionnaires were administered. Of these, 41 were excluded for one or more of the following reasons: the respondent discontinued before completion, had ceased rice cultivation at the time of the survey, cultivated only dryland crops without paddy, or returned responses with missing or outlier values on key items. The final analysis sample comprises 1066 valid questionnaires, an effective response rate of 96.3%. With three choice tasks per respondent and three alternatives per task, the analysis dataset comprises $1066 \times 3 \times 3 = 9594$ alternative-level observations. The geographical distribution of the survey sites is shown in Figure 1.

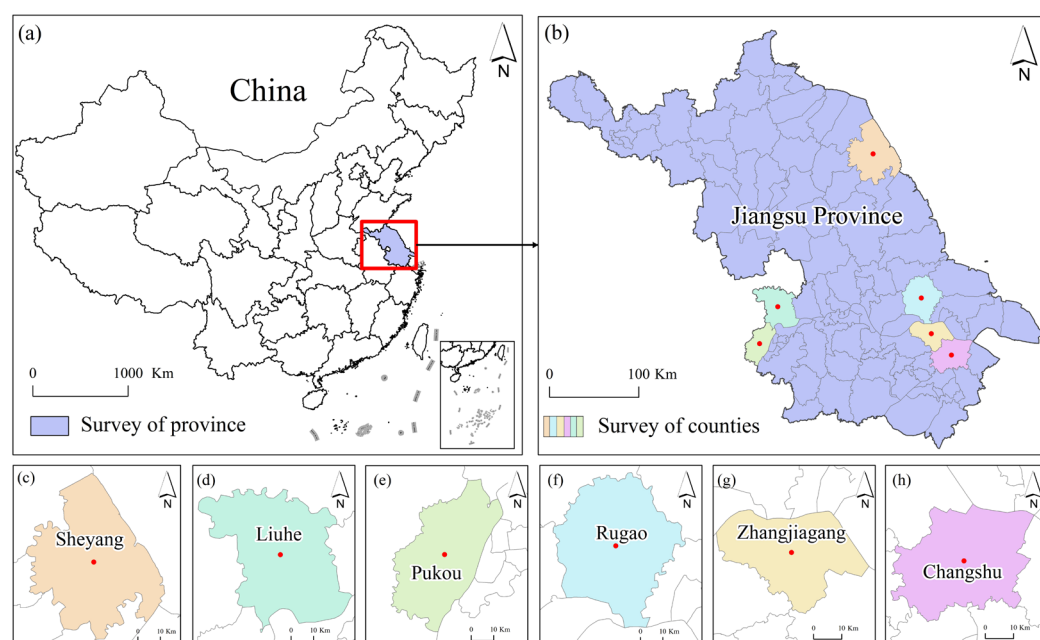


Figure 1. Study area: surveyed counties and districts in Jiangsu Province. Notes: (a) Location of Jiangsu Province within China. (b) The six surveyed administrative units within Jiangsu—Sheyang (Yancheng) in northern Jiangsu, Rugao (Nantong) in central Jiangsu, Zhangjiagang and Changshu (Suzhou) in southern Jiangsu, and Liuhe and Pukou under the jurisdiction of Nanjing. (c–h) Detailed administrative shapes of the six surveyed units. Red dots indicate the centroids of the surveyed units.

2.2. Choice-Experiment Design

2.2.1. Attributes and Levels

The attribute set was informed by three sources: (i) review of the existing CE literature on fertilizer reduction and agri-environmental compensation [21,23]; (ii) review of national and provincial policy documents specifying reduction pathways and available subsidy instruments [27,28]; and (iii) semi-structured interviews with extension officials and focus-group discussions with rice-farming households conducted prior to questionnaire finalization. This process yielded eight attributes organized into four conceptual

groups: five reduction-measure attributes, one support-service attribute, one compensation-mode attribute, and one compensation-level attribute (Table 1).

Table 1. Attributes and levels of the choice experiment.

Attribute		Definition	Levels
Reduction-measure bundle	Soil-testing-based fertilization (x_1)	Adoption of soil-testing-based formulated fertilization, a precision technique that adjusts NPK application according to soil test recommendations.	Not adopted; Adopted
	Deep placement (x_2)	Adoption of mechanized deep placement of fertilizer, which delivers fertilizer below the soil surface to reduce volatilization and runoff.	Not adopted; Adopted
	Organic substitution (x_3)	Partial substitution of chemical fertilizer with organic fertilizer (commercial organic fertilizer or composted manure).	Not adopted; Adopted
	Crop rotation (x_4)	Implementation of rice-based rotation in which a non-rice crop is grown on the same paddy following the rice harvest.	Not adopted; Adopted
	Straw return (x_5)	Mechanized incorporation of crop straw into the soil after harvest to enhance organic matter and reduce mineral-fertilizer demand.	Not adopted; Adopted
Support service		Form of technical support provided to farmers adopting the measures above.	Centralized classroom training; On-site field guidance
Compensation mode		Form in which compensation is delivered to participating farmers.	Income subsidy; Price subsidy; Input subsidy
Compensation level		Share of the alternative-specific incremental adoption cost reimbursed by the program.	0%, 30%, 50%, 80%, 100%

Notes: Attributes and levels were developed based on the literature review, policy documents, and pre-survey focus groups described in the text. The notation $x_1, \dots, x_5$ refers to the five binary reduction-measure indicators used in the utility specification (Equation (3), Section 2.3).

Within the reduction-measure group, the five practices were chosen by matching the technical pathways prescribed in China's national fertilizer-reduction action plans (the Action Plan for Zero Growth in Fertilizer Use by 2020 and the subsequent Action Plan for Fertilizer Reduction by 2025) against the reduction technologies actually promoted in Jiangsu and the agronomic characteristics of the province's rice systems. Each corresponds to a concrete, deployable policy instrument: soil-testing-based (formula) fertilization is the flagship instrument of the Ministry of Agriculture and Rural Affairs under the national Soil Testing and Formula Fertilization Program; deep placement is promoted as a core efficiency-raising agronomic technique; organic substitution is the centerpiece of the organic-fertilizer-replacing-chemical-fertilizer pilots; straw return is supported through comprehensive straw-utilization subsidies; and crop rotation is promoted under the cropland rotation-and-fallow pilot program [27,28]. Because these are instruments program designers can actually deploy, the measure-specific WTA estimates recovered below translate directly into policy levers.

Having identified these five measures, the first design choice concerns how they are represented in the experiment. As noted in the Introduction, existing CE applications to fertilizer reduction typically operationalize reduction either as a single aggregate attribute

or as a set of mutually exclusive technical alternatives, neither of which captures the combinatorial nature of on-farm adoption decisions. We instead treat each of the five fertilizer-reduction measures as a separate binary attribute (adopt/do not adopt), allowing any policy alternative to combine an arbitrary subset of the five. This multi-binary-attribute structure preserves the realism of farmer adoption and recovers measure-specific marginal-utility estimates that are directly comparable across practices.

The second design choice involves the framing of the compensation attribute, which connects directly to the policy context of the experiment. China's existing fertilizer-reduction support is delivered predominantly through fixed monetary subsidies tied to specific measures: in Jiangsu, mechanized straw return is reimbursed at 10–25 CNY/mu (1 mu $\approx$ 0.067 ha), ecological deep plowing at a flat 40 CNY/mu [28], and organic substitution at approximately 100 CNY/mu under pilot programs of the Ministry of Agriculture and Rural Affairs [27]. Flat-rate designs offer clear administrative advantages: predictability, ease of implementation, and avoidance of farm-specific cost verification. At the same time, fixed amounts are constrained by the cost benchmarks used to set them and may diverge from actual adoption costs as production conditions evolve, a concern that has motivated continuing interest in cost-linked compensation structures [23]. Internationally, the U.S. Environmental Quality Incentives Program (EQIP) provides cost-share assistance covering up to 75% of approved practice costs [29]; within China, related cost-share logic operates in adjacent policy areas such as agricultural-insurance premiums and machinery scrappage. Against this background, presenting compensation as a share of incremental adoption cost is methodologically attractive: it anchors the choice task to costs that respondents understand, and yields monetary-scale parameters interpretable across the bundle of measures considered. The per-measure incremental cost benchmarks (in CNY/mu) were set at 30 for soil-testing-based fertilization, 50 for deep placement, 150 for organic substitution, 200 for crop rotation, and 30 for straw return, based on local market prices, pre-survey focus groups, and consultations with extension officials. We emphasize that this is a measurement choice rather than a policy recommendation; it serves to elicit preferences cleanly, not to advocate for cost-share over flat-rate program structures in practice.

Beyond the fertilizer-reduction measures and the compensation level, two further attributes capture program-design features that systematically vary across actual fertilizer-reduction programs in China and that the broader CE literature has shown to be material to farmer participation [21,23]. The first is the form of technical assistance bundled with the policy alternative, an attribute consistently found to be valued by farmers in agri-environmental schemes [19,23]. Blazy et al. [14], in a CE on soil-carbon-sequestration policy, found that adding technical-support provisions to the contract raises participation by approximately 30 percentage points and is valued at substantially more than its delivery cost, underscoring the importance of separating support mode from payment level when modeling farmer responses. We retain the two delivery modes that account for the bulk of extension activity in Chinese rice-growing regions: centralized training (group sessions held at the township or village level) and on-site field guidance (extension agents visiting individual farms during the season). The two modes differ on dimensions (coverage versus depth, cost per farmer reached, and the tacit-knowledge content of the support delivered) that respondents in our pre-survey focus groups identified as practically meaningful.

The second is the form of compensation, which in Chinese fertilizer-reduction programs takes three broadly distinct forms: income subsidies paid directly to participating households as decoupled cash transfers, price subsidies operating through output premiums or input-price discounts, and input subsidies delivered as free or discounted inputs such as discounted organic fertilizer or fully subsidized service-provider arrangements.

These three modes correspond to the principal ways that fertilizer-reduction support is currently delivered on the ground [27] and differ in implications for household liquidity, transaction costs of contracting and verifying practice adoption, and the targeting of the transfer. Because income subsidy is the omitted reference category (Section 2.3.1), the negative price- and input-subsidy coefficients indicate that respondents prefer an income subsidy to either alternative mode of equal monetary value.

2.2.2. Experimental Design

With six binary attributes (the five fertilizer-reduction measures plus the binary support-service attribute), one three-level attribute (compensation mode), and one five-level attribute (compensation level), a full-factorial design would generate $2^6 \times 3 \times 5 = 960$ distinct alternative profiles, which are too many for feasible field implementation. We therefore employed a D-efficient fractional-factorial design generated using Ngene 1.2 [30], which yielded 36 binary choice tasks, each consisting of two unlabeled experimental alternatives, following best-practice recommendations for stated-preference design [31]. The design assumes uninformative (zero) priors for all attribute coefficients, consistent with the absence of strong ex ante information about preference magnitudes in this specific setting; orthogonality and level balance were verified post-generation.

A design that is D-efficient under zero priors is not guaranteed to remain D-efficient at the true parameter values, which the estimation shows to depart substantially from zero. In the absence of credible priors for this multi-binary setting, the zero-prior design is the conventional choice, and the precision of the resulting estimates (see Section 3.2) indicates that it supported efficient estimation in practice.

To each of the 36 binary choice tasks we appended a status-quo alternative (“Choice C: do not participate in any reduction program”) in which all five fertilizer-reduction measures are not adopted and the compensation amount is zero, yielding 36 three-alternative choice sets in total. To reduce respondent burden while preserving statistical efficiency at the sample level, we partitioned the 36 choice sets into 12 blocks of three sets each, with each respondent randomly assigned to one block. The decision to administer three tasks per respondent reflects a deliberate trade-off between estimation efficiency and respondent burden in a population where formal schooling is generally limited and field conditions impose practical limits on interview duration; the relatively small per-respondent task load is offset by the comparatively large sample of 1066 respondents [11]. An example choice set, as presented to respondents, is shown in Table 2.

A power analysis based on established choice-experiment sample-size guidance [32,33] supports this configuration: the rule-of-thumb minimum for main-effects estimation ($n \geq 500c/(t \cdot a)$, with c the largest number of attribute levels, t the number of choice tasks per respondent, and a the number of alternatives per task) implies roughly 278–417 respondents, which the realized sample of 1066 exceeds severalfold, and all eight random-parameter standard deviations are estimated precisely and are significant at the 1% level (see Section 3.2).

Table 2. Example of a choice set as presented to respondents.

Attribute	Alternative A	Alternative B	Alternative C (Status Quo)
Reduction-measure bundle	Soil-testing-based fertilization; Organic substitution	Deep placement; Crop rotation; Straw return	None
Support service	On-site field guidance	Centralized classroom training	Not applicable
Compensation mode	Price subsidy	Input subsidy	Not applicable
Compensation level	30% of incremental cost	50% of incremental cost	0%

Please tick your preferred option	☐	☐	☐
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Notes: Generated by the authors as an illustrative example. The actual choice cards presented to respondents included the per-mu monetary equivalent of each compensation share, computed from the per-measure incremental cost benchmarks reported in Section 2.2.1.

2.2.3. Questionnaire and Survey Implementation

The survey was conducted from October 2024 through March 2025, with a pilot study administered beforehand at a rice-farming cooperative in Liuhe District, Nanjing, to refine item wording and ordering before the main fieldwork commenced. The final questionnaire collects respondent and farm-operation characteristics used as covariates in the heterogeneity analysis (age, gender, education, household labor, farming experience, village-cadre status, rice-cultivated area, household income, and share of household income from agriculture), together with the core choice-experiment block in which respondents complete the three choice tasks corresponding to their randomly assigned block after being briefed on attribute definitions and per-measure incremental costs.

To mitigate hypothetical bias, we followed protocols established in the stated-preference literature [34–36]: a “cheap-talk” reminder describing how stated preferences may diverge from real budget-constrained choices (adapted to the rural Chinese context), and a budget reminder asking respondents to consider their actual financial circumstances. For respondents who selected the status-quo alternative across all three choice sets, a follow-up item elicited reasons, allowing protest responses to be distinguished from substantive zero-bid preferences.

Of the 1107 questionnaires initiated, 41 were excluded after standard data-quality screening, yielding the final sample of 1066 valid responses (96.3% effective response rate).

2.3. Econometric Framework

2.3.1. Random Utility Framework

The analysis builds on the random utility framework grounded in Lancaster’s [8] characteristics theory of value [10–12]. Throughout the model, we let $n = 1, \dots, N$ index respondents ($N = 1066$); $t = 1, \dots, T$ index choice tasks completed by each respondent ($T = 3$); $j \in C_t$ index alternatives within choice set t , where C_t contains the two designed alternatives plus the status-quo alternative ($|C_t| = 3$); $i = 1, \dots, 5$ index the five fertilizer-reduction measures; and $k \in C_t$ index alternatives in the denominator of the choice probability. Under this notation, the utility respondent n derives from alternative j in choice set t is decomposed into a systematic component V_{njt} and a random component ε_{njt} :

$$U_{njt} = V_{njt} + \varepsilon_{njt} \quad (1)$$

where ε_{njt} is the assumed i.i.d. extreme value. The probability that respondent n chooses alternative j in choice set t takes the standard logit form:

$$P_{njt} = \exp(V_{njt}) / \sum_k \exp(V_{nkt}) \quad (2)$$

The systematic utility for our specification is:

$$V_{njt} = \alpha \cdot ASC_j + \sum_{i=1}^5 \beta_i \cdot x_{ijt} + \gamma_1 \cdot service_field_{jt} + \gamma_2 \cdot subsidy_price_{jt} + \gamma_3 \cdot subsidy_input_{jt} + \delta \cdot compensation_{jt} \quad (3)$$

where ASC_j is an alternative-specific constant equal to one for the status-quo alternative and zero otherwise, capturing the average effect of factors not included as explicit attributes (generalized inertia, uncertainty aversion); x_{ijt} is the binary indicator for measure i in alternative j of choice set t , taking the value one if measure i is included in that alternative and zero otherwise; $service_field_{jt}$ equals one if alternative j offers on-site field

guidance and zero if it offers centralized training (the reference category); $subsidy_price_{jt}$ and $subsidy_input_{jt}$ are dummies for price subsidy and input subsidy modes, with income subsidy as the reference category; and $compensation_{jt} = (\sum_i x_{ijt} \cdot c_i) \cdot rate_{jt}$ is the actual monetary compensation, in CNY/mu, derived from the bundle of measures included in alternative j and the announced compensation rate, where c_i denotes the per-mu incremental adoption cost of measure i (Section 2.2.1) and $rate_{jt} \in \{0, 0.30, 0.50, 0.80, 1.00\}$ is the cost-share rate. For the status-quo alternative, all reduction-measure indicators are zero, the service and subsidy-mode dummies take their reference values, and $compensation_{jt}$ equals zero. The Greek letters α , $\beta = (\beta_1, \dots, \beta_5)$, $\gamma = (\gamma_1, \gamma_2, \gamma_3)$, and δ are the parameters to be estimated.

Equation (3) specifies utility as additively separable in the five measures, with no interaction terms. This is consistent with the combinatorial intent of the multi-binary design and preserves both estimation tractability and the interpretation of each β_i as a practice-specific marginal utility. It does abstract from possible agronomic complementarities or substitutabilities between practices (for example, the overlapping nutrient pathways of straw return and organic substitution), which we revisit in the limitations (Section 5).

Two identification considerations follow from this construction. First, because $compensation_{jt}$ is itself a function of both the measure-bundle indicators x_{ijt} and the announced rate $rate_{jt}$, the coefficient β_i on each reduction-measure attribute is to be interpreted as the marginal utility of adopting measure i conditional on the monetary cost-share component already being absorbed into the compensation term. Substantively, β_i captures the non-monetary preference for or against measure i (operational inconvenience, perceived risk, social-norm influences, and prior experience) rather than the full preference inclusive of cost expectations, which is partitioned into the compensation channel via δ . Second, the separate identification of β_i and δ relies on the variation of $rate_{jt}$ across the five levels $\{0, 0.30, 0.50, 0.80, 1.00\}$, which is built into the experimental design with sufficient orthogonality (Section 2.2.2) to support stable estimation.

Specifically, δ is identified from variation in the rate across alternatives holding the bundle constant: two alternatives with the same measures share the same non-monetary utility but differ in compensation, so their contrast isolates δ . Conversely, β_i is identified from the presence versus absence of measure i across alternatives holding the rate constant, net of its mechanical contribution to compensation. This orthogonality of rate against bundle keeps the measure indicators and the compensation term from being collinear, so β_i and δ can be estimated separately.

2.3.2. Mixed Logit Specification

To accommodate preference heterogeneity across respondents [11,12,23,37,38], we estimate Equation (3) using a mixed-logit (MXL) specification. Under MXL, a subset of the coefficients is treated as random with respondent-specific values drawn from a specified distribution, and the means and standard deviations of these distributions are estimated from the data. Letting $j(t)$ denote the alternative actually chosen by respondent n in choice set t , and letting θ denote the parameters governing the distribution $f(\beta | \theta)$ of the random coefficients, the probability of the observed sequence of choices for respondent n is the integral of the conditional logit probability over that distribution:

$$L_n(\theta) = \int \prod_t P_{nj} * (t), t(\beta) \cdot f(\beta | \theta) d\beta \quad (4)$$

We approximate this integral via maximum simulated likelihood with 1000 Halton draws [11]. The stability of the estimates with respect to the number of simulation draws was confirmed by re-estimating the model with alternative numbers of Halton draws, which left the parameter estimates and their standard errors substantively unchanged. We treat the five fertilizer-reduction measures $(\beta_1, \dots, \beta_5)$, the service-mode parameter

(γ_1), and the two subsidy-mode parameters (γ_2, γ_3) as random parameters following normal distributions, on the grounds that preferences over reduction practices and program-design features are likely to vary substantially across respondents in a heterogeneous farming sample. The compensation coefficient (δ) and the alternative-specific constant (α) are treated as fixed parameters: the former to ensure a stable monetary scale for WTA computation, and the latter to maintain interpretability of the status-quo effect.

2.3.3. Heterogeneity by Farm-Operation Scale

A central source of preference heterogeneity in our sample is the dual structure of contemporary Chinese rice production: smallholder households coexisting with NAOEs. Smallholders typically face tighter cash constraints, lower mechanization, and stronger reliance on off-farm income; NAOEs have greater scale-related access to extension services, credit, and equipment. These structural differences may generate distinct preference patterns over fertilizer-reduction measures, support modes, and compensation structures. To investigate this dimension, we re-estimate the MXL model separately on the smallholder subsample ($n = 481$) and the NAOE subsample ($n = 585$), and compare the corresponding parameter estimates and WTA values. We also estimate an interaction-augmented specification on the full sample in which the ASC interacts with respondent age, education, and share of household income from agriculture to characterize how individual-level characteristics shape the baseline preference for participation versus the status quo.

In this specification, observed individual characteristics enter only through the ASC and so capture heterogeneity in the propensity to participate, while practice-specific preference heterogeneity is captured by the random-parameter standard deviations of the mixed logit. Individual characteristics are not interacted with the measure or subsidy coefficients, since the random parameters already absorb practice-level heterogeneity, as confirmed by the stability of the measure coefficients across Models 1 and 2 (Section 3.3).

2.3.4. Willingness-to-Accept Calculations

For any non-monetary attribute l with coefficient $\rho l \in \{\beta_1, \dots, \beta_5, \gamma_1, \gamma_2, \gamma_3\}$, the willingness-to-accept measure (the additional compensation, in CNY/mu, that leaves the respondent indifferent over the attribute, holding all other attributes fixed) is:

$$WTAl = -\rho l / \delta \quad (5)$$

For attributes where $\rho l < 0$ (adoption imposes net non-monetary costs), $WTAl$ is positive and represents the minimum compensation required to induce adoption. For attributes where $\rho l > 0$, indicating positive utility relative to the reference category, the corresponding ratio expresses a willingness-to-pay (the compensation respondents would forgo to obtain the attribute). Both quantities are derived from Equation (5); we interpret them by sign. The 90% confidence intervals for WTA values are constructed using the delta method, as implemented in the wtp post-estimation routine following Hole [39]. The choice of 90% rather than 95% follows Schenker and Gentleman [40], who note that the conventional 95%-interval visual inspection systematically overstates apparent overlap when the inferential question is whether two group estimates differ. All MXL models are estimated in Stata 16.0; standard errors are clustered at the respondent level to account for within-respondent correlation across the three choice tasks.

3. Results

3.1. Sample Characteristics

The 1066 valid respondents are distributed across the six counties and districts, and across two structural categories: 481 smallholders (45.1%) and 585 NAOEs (54.9%). The

latter group comprises specialized large planters (242, 22.7%), family farms, cooperatives, and agricultural enterprises (jointly 343, 32.2%). Because smallholder households greatly outnumber NAOEs in the population, the sample was not drawn in proportion to the two operator types; their relative shares were instead controlled at the sampling stage (Section 2.1) so that each subsample was large enough for the operator-type comparison. The reported composition therefore reflects this analytical design rather than the population shares of the two groups.

Table 3 presents key respondent characteristics. The sample is predominantly male (85.2%), with most respondents in the 55–69 age range (49.1%). Educational attainment is concentrated at middle-school level (47.6%), with 11.6% holding tertiary education or above. Rice-cultivation experience is extensive: 39.3% of respondents have farmed for more than 30 years. Rice-cultivation area shows substantial right-skewness: the mean is 247.5 mu (≈ 16.5 ha), the median 110 mu, with a maximum of 4000 mu, reflecting the coexistence of smallholder plots and large operations. The area distribution is, however, sharply bimodal across operator types: 87.1% of smallholders cultivate fewer than 30 mu (median 5 mu), while 92.0% of NAOEs cultivate at least 100 mu (median 300 mu), with 27.8% of NAOEs operating 500 mu or more. Only 4.0% of smallholders and 8.0% of farms in the 30–100 mu range fall in the overlap zone, confirming that the distinction between smallholders and NAOEs adopted in the analysis aligns closely with the underlying scale partition rather than being a label imposed on a continuous distribution. Annual rice income similarly shows wide dispersion (mean 266,221 CNY; median 75,000 CNY), driven by scale.

Table 3. Sample characteristics ($N = 1066$).

Variable	Description	%/Mean
Age	25–39	5.6%
	40–54	30.6%
	55–69	49.1%
	70–84	14.7%
Gender	Male	85.2%
	Female	14.8%
Household labor	1	9.5%
	2	51.5%
	3	19.7%
	4 or more	19.3%
Education	None/illiterate	4.5%
	Primary school	17.4%
	Middle school	47.6%
	High school	19.0%
	Tertiary or above	11.6%
Rice area (mu)	Mean	247.5
	Median	110
	<30 mu	41.3%
	30–100 mu	6.2%
	100–500 mu	36.9%
	≥ 500 mu	15.6%
Rice income (CNY/year)	Mean	266,221
	Median	75,000
Farming experience	<3 years	3.3%
	4–10 years	24.3%
	11–20 years	20.5%

	21–30 years	12.6%
	>30 years	39.3%
Operation type	Smallholder	45.1%
	NAOE	54.9%

Note: (1) Total respondents $N = 1066$. (2) $1 \text{ mu} \approx 0.067 \text{ ha}$; $1 \text{ USD} \approx 7.30 \text{ CNY}$ (January 2025 reference rate). (3) The classification of respondents into smallholders and NAOEs follows the definition adopted in the 2017 Third National Agricultural Census; the NAOE pool comprises specialized large planters, family farms, cooperatives, and agricultural enterprises. (4) Within-operator percentages in the area-bin rows are conditional on operator type (column percentages); the lead value is the share of all respondents in that bin.

Of the 1066 respondents, only 5.5% selected the status-quo alternative across all three choice tasks, and follow-up items indicated that the majority of these expressed reasoned zero-bid preferences rather than protest motives. We therefore retain all observations in the analysis sample.

3.2. Mixed Logit Estimates: Full Sample

Table 4 reports the mixed-logit estimates for the full sample under three specifications. Model 1 is the baseline with no individual-characteristic interactions. Model 2 augments the alternative-specific constant (ASC) with all eight collected respondent characteristics. Model 3 retains only the three interactions individually significant in Model 2 (age, education, and agricultural-income share), with the five jointly insignificant interactions (gender, household labor count, village-cadre status, farming experience, and household income) dropped; cells marked with an em-dash indicate that the corresponding interaction is not included in that specification. The discussion below focuses on Model 1; the interaction-augmented specifications are taken up in Section 3.3.

Table 4. Mixed-logit estimates—full sample, three specifications.

Variable	Model 1		Model 2		Model 3	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
<i>Fixed Parameter</i>						
Compensation (CNY/mu)	0.015 ***	(0.002)	0.015 ***	(0.002)	0.015 ***	(0.002)
ASC (status quo)	−3.674 ***	(0.306)	−5.011 ***	(1.315)	−4.888 ***	(1.211)
ASC × Age	—		0.037 **	(0.017)	0.043 ***	(0.014)
ASC × Gender	—		0.316	(0.395)	—	
ASC × Household labor	—		0.052	(0.109)	—	
ASC × Village cadre	—		0.009	(0.436)	—	
ASC × Farming experience	—		0.046	(0.107)	—	
ASC × Education	—		−0.291 *	(0.176)	−0.288 *	(0.174)
ASC × Household income	—		−0.035	(0.071)	—	
ASC × Ag income share	—		−0.162 *	(0.090)	−0.161 *	(0.086)
<i>Random Parameters—Means</i>						
Soil-testing-based fertilization	0.359 **	(0.139)	0.328 **	(0.130)	0.329 **	(0.131)
Deep placement	−0.017	(0.137)	−0.010	(0.128)	−0.010	(0.129)
Organic substitution	−1.396 ***	(0.193)	−1.355 ***	(0.184)	−1.360 ***	(0.184)
Crop rotation	−2.286 ***	(0.262)	−2.188 ***	(0.245)	−2.196 ***	(0.246)
Straw return	−0.282 **	(0.129)	−0.271 **	(0.122)	−0.273 **	(0.122)
Service: field guidance	0.183	(0.139)	0.176	(0.131)	0.176	(0.132)
Price subsidy	−0.532 ***	(0.185)	−0.536 ***	(0.176)	−0.538 ***	(0.176)
Input subsidy	−0.613 ***	(0.167)	−0.588 ***	(0.157)	−0.590 ***	(0.158)

Random Parameters—Standard deviations

Soil-testing-based fertilization	1.755 ***	(0.276)	1.647 ***	(0.267)	1.660 ***	(0.267)
Deep placement	1.906 ***	(0.312)	1.733 ***	(0.291)	1.743 ***	(0.291)
Organic substitution	1.774 ***	(0.262)	1.664 ***	(0.244)	1.672 ***	(0.244)
Crop rotation	1.671 ***	(0.301)	1.538 ***	(0.280)	1.550 ***	(0.280)
Straw return	1.472 ***	(0.289)	1.356 ***	(0.272)	1.368 ***	(0.274)
Service: field guidance	2.242 ***	(0.291)	2.141 ***	(0.273)	2.147 ***	(0.274)
Price subsidy	2.898 ***	(0.408)	2.738 ***	(0.379)	2.756 ***	(0.382)
Input subsidy	1.742 ***	(0.313)	1.621 ***	(0.305)	1.621 ***	(0.305)
<i>Model statistics</i>						
Observations	9594		9594		9594	
Log-likelihood	−2500.25		−2486.14		−2486.77	
AIC	5036.51		5022.29		5015.55	
BIC	5165.55		5187.21		5166.09	

Notes: (1) Standard errors are reported in parentheses. (2) ***, **, * indicate significance at 1%, 5%, and 10% levels, respectively. (3) Estimation is based on 1000 Halton draws; standard errors are clustered at the respondent level.

The compensation coefficient is positive and highly significant ($\delta = 0.0150$, $p < 0.001$), confirming that respondents value monetary compensation and validating the cost-proportional design's identification of monetary preferences. The alternative-specific constant on the status-quo alternative is strongly negative ($\alpha = -3.674$), indicating substantial baseline aversion to the status quo, consistent with widespread perception in the sample that current fertilizer use is excessive.

Among the five reduction-measure coefficients (each interpretable as the non-monetary component of the preference, since the monetary value of compensation is already in the utility function), a clear pattern emerges. Soil-testing-based fertilization ($\beta_1 = 0.359$, $p = 0.010$) is the only measure with a significantly positive non-monetary coefficient. Adoption raises utility before the corresponding compensation is received, suggesting that respondents associate this technique with intrinsic benefits (yield improvement and cost saving on excess fertilizer). Deep placement ($\beta_2 = -0.017$, $p = 0.904$) has a non-monetary coefficient indistinguishable from zero, suggesting that the cost-share component of compensation offsets any residual non-monetary aversion. Organic substitution ($\beta_3 = -1.396$, $p < 0.001$) and crop rotation ($\beta_4 = -2.286$, $p < 0.001$) carry strongly negative non-monetary coefficients, indicating substantial residual aversion beyond the monetary compensation; rotation has the largest negative coefficient of any measure. For these measures, a more negative coefficient indicates a stronger disutility from the practice and hence a larger compensation, recovered as the WTA in Section 3.4, required to induce its adoption. Straw return ($\beta_5 = -0.282$, $p = 0.028$) is mildly negative.

The service-mode dummy is positive but not significant ($\gamma_1 = 0.183$), suggesting that respondents are roughly indifferent between on-site field guidance and centralized training. Among subsidy modes, both the price-subsidy dummy ($\gamma_2 = -0.532$, $p = 0.004$) and the input-subsidy dummy ($\gamma_3 = -0.613$, $p < 0.001$) are significantly negative, indicating that respondents prefer income subsidies over price or input alternatives—a finding with direct policy implications discussed in Section 4.

The lower panel of Table 4 reports the estimated standard deviations of the random parameters; following standard convention, we interpret these as positive regardless of the estimated sign. All eight standard deviations are highly significant ($p < 0.001$), indicating substantial preference heterogeneity for every reduction measure, the support-service mode, and both subsidy modes. The magnitudes, ranging from 1.47 to 2.90, imply that respondent-specific preferences span both signs around each estimated mean. For example, while the mean coefficient on rotation is strongly negative (−2.29), the estimated

standard deviation of 1.67 implies that, under the assumed normal distribution, about 8.6% of respondents hold a positive non-monetary preference for rotation (equivalently, a negative WTA). The corresponding shares are about 21.6% for organic substitution and 42.4% for straw return, confirming that a substantial minority hold practice-specific preferences that diverge in sign from the estimated means. The fact that heterogeneity is significant across all attributes underscores the limitation of single-point compensation standards and motivates differentiated payments by farmer type.

3.3. Preference Heterogeneity by Individual Characteristics

Model 3 of Table 4 augments the baseline with three ASC interaction terms (respondent age, education, and share of household income derived from agriculture) retained from a full eight-interaction specification (Model 2) after the remaining five interactions were found to be jointly insignificant. The pattern is intuitive and consistent with the broader behavioral literature on agri-environmental adoption.

Both interaction-augmented specifications improve significantly on the baseline (Model 2 vs. Model 1: LR = 28.22, df = 8, $p < 0.001$; Model 3 vs. Model 1: LR = 26.96, df = 3, $p < 0.001$), while the restriction from Model 2 to the more parsimonious Model 3 cannot be rejected (LR = 1.26, df = 5, $p = 0.94$), indicating that the five interactions excluded in Model 3 are jointly insignificant. Model 3 is therefore preferred on the likelihood-ratio criterion, consistent with its attaining the lowest AIC among the three specifications.

Age strengthens the status-quo bias ($ASC \times Age = 0.043$, $p = 0.003$): each additional year of respondent age makes participation in any reduction program less attractive relative to the status quo. This is consistent with risk aversion, learning costs, and habituation increasing with age and aligns with the broader literature on status-quo bias in decision-making [41]. Education weakens the status-quo bias ($ASC \times Education = -0.288$, $p = 0.097$): more-educated respondents are more open to participation, possibly through awareness of environmental externalities or higher capacity to understand new practices. Agricultural-income share also weakens the status-quo bias ($ASC \times Ag\ income\ share = -0.161$, $p = 0.062$): respondents whose livelihood depends more heavily on agriculture are more willing to participate. While this finding might appear counterintuitive at first (one might expect cash-constrained agricultural households to be more risk-averse), it is consistent with a “skin-in-the-game” interpretation: respondents whose income is dominated by farming have a stronger stake in the long-term productivity of their soil, internalizing the benefits of fertilizer reduction more fully than respondents with substantial off-farm income.

The five reduction-measure coefficients and the support and subsidy parameters are stable across Models 1 and 2, indicating that preference heterogeneity over individual measures is driven by unobserved factors captured in the random-parameter standard deviations rather than by the observed individual characteristics interacted here.

3.4. Willingness-to-Accept Estimates

Table 5 reports the WTA estimates derived from the baseline specification, expressed in CNY/mu. The values are interpretable as the additional compensation, beyond the monetary cost-share component already absorbed into the compensation channel, that is required to leave the respondent indifferent over the inclusion of each attribute. WTA values are positive when the underlying coefficient is negative (adoption requires inducement); they are negative when the underlying coefficient is positive (the attribute itself confers utility, and the respondent would, in principle, “pay” to receive it).

Table 5. Willingness-to-accept estimates—full sample (CNY/mu).

Attribute	WTA	90% Confidence Interval
Status quo (ASC)	244.75	[213.45, 276.06]
Soil-testing-based fertilization	−23.94	[−39.04, −8.83]
Deep placement	1.10	[−13.88, 16.08]
Organic substitution	93.01	[79.23, 106.79]
Crop rotation	152.27	[137.50, 167.04]
Straw return	18.79	[5.24, 32.35]
Service: field guidance	−12.18	[−27.00, 2.64]
Price subsidy	35.42	[15.73, 55.11]
Input subsidy	40.81	[23.45, 58.18]

Notes: (1) WTA values are computed as $-\beta/\delta$ from the Model 1 baseline mixed-logit estimates (Table 4) and are expressed in CNY/mu. (2) 90% confidence intervals (in brackets) are constructed using the delta method as implemented in the wtp post-estimation routine following Hole [39]. (3) 1 mu $\approx$ 0.067 ha.

The full-sample WTA estimates in Table 5 yield a clear ordering across the five fertilizer-reduction measures. Crop rotation tops the ranking at 152.27 CNY/mu, followed by organic substitution at 93.01 and straw return at 18.79, with deep placement at 1.10 (statistically zero) and soil-testing-based fertilization at −23.94 CNY/mu. The negative value for soil-testing-based fertilization is a willingness-to-pay rather than a willingness-to-accept, indicating that respondents would forgo up to 24 CNY/mu of compensation to ensure inclusion of this measure: soil testing is intrinsically valued. The ordering tracks the perceived operational burden of each practice, from the substantial cropping-system reorganization required by rotation down to the simple decision-rule change implied by soil testing. Notably, the WTA for rotation substantially exceeds existing flat-rate subsidies for any reduction practice in Jiangsu (the highest is approximately 100 CNY/mu for organic substitution under ministry-level pilot programs), indicating that rotation cannot be effectively promoted under existing payment structures. Beyond the practice attributes, the comparison across subsidy modes is similarly informative: both the price-subsidy (35.42 CNY/mu) and input-subsidy (40.81 CNY/mu) modes carry positive WTA values relative to the income-subsidy reference, implying that switching from income subsidy to either alternative form would impose a non-trivial welfare cost on respondents and confirming that income subsidies dominate in respondent preferences. Finally, the point estimate for service mode (−12.18 CNY/mu) leans toward field guidance over centralized training, but the confidence interval crosses zero, consistent with the insignificant underlying coefficient.

3.5. Subsample Analysis: Smallholders Versus NAOEs

To explore preference heterogeneity along the key structural dimension distinguishing contemporary Chinese rice operators, we re-estimated the baseline mixed-logit specification separately on the smallholder ($n = 481$, 4329 observations) and NAOE ($n = 585$, 5265 observations) subsamples. Table 6 reports the comparison of estimates and Figure 2 visualizes the corresponding WTA values.

Table 6. Mixed-logit estimates—subsample comparison.

Variable	Smallholders		NAOEs	
	Coeff.	S.E.	Coeff.	S.E.
<i>Fixed Parameter</i>				
Compensation (CNY/mu)	0.018 ***	(0.004)	0.013 ***	(0.002)
ASC (status quo)	−4.665 ***	(0.920)	−3.299 ***	(0.289)

<i>Random Parameters—Means</i>				
Soil-testing-based fertilization	0.189	(0.292)	0.395 ***	(0.143)
Deep placement	−0.562	(0.353)	0.157	(0.136)
Organic substitution	−1.199 ***	(0.401)	−1.455 ***	(0.206)
Crop rotation	−3.092 ***	(0.745)	−1.860 ***	(0.241)
Straw return	−0.521 *	(0.291)	−0.182	(0.128)
Service: field guidance	0.535	(0.333)	0.069	(0.134)
Price subsidy	−1.009 **	(0.409)	−0.331 *	(0.189)
Input subsidy	−0.740 **	(0.353)	−0.501 ***	(0.172)
<i>Random Parameters—Standard deviations</i>				
Soil-testing-based fertilization	2.256 ***	(0.763)	1.435 ***	(0.274)
Deep placement	2.926 ***	(0.731)	1.172 ***	(0.305)
Organic substitution	2.952 ***	(0.824)	1.131 ***	(0.273)
Crop rotation	2.704 ***	(0.826)	1.107 ***	(0.286)
Straw return	2.146 ***	(0.651)	1.009 ***	(0.306)
Service: field guidance	4.033 ***	(0.948)	1.149 ***	(0.300)
Price subsidy	3.859 ***	(0.935)	2.134 ***	(0.375)
Input subsidy	2.529 **	(0.989)	1.388 ***	(0.337)
<i>Model statistics</i>				
Observations	4329		5265	
Log-likelihood	−1142.18		−1330.06	
AIC	2320.35		2696.11	
BIC	2435.07		2814.35	

Note: (1) Standard errors are reported in parentheses. (2) ***, **, * indicate significance at 1%, 5%, and 10% levels, respectively. (3) Estimation is based on 1000 Halton draws; standard errors are clustered at the respondent level. (4) Smallholder $n = 481$ (4329 observations); NAOE $n = 585$ (5265 observations). The full-sample baseline estimates are reported in Table 4 (Model 1). (5) 1 mu $\approx$ 0.067 ha.

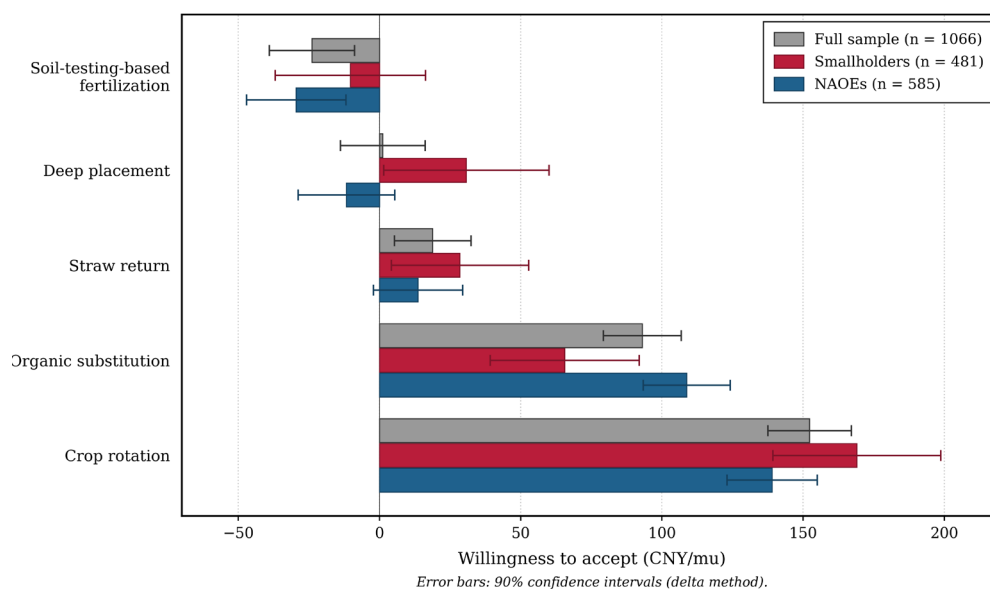


Figure 2. Willingness-to-accept estimates by farm-operation type. Notes: (1) Estimates are reported in CNY/mu with 90% confidence intervals. (2) Three series are shown: full sample ($n = 1066$; reproducing Table 5), smallholders ($n = 481$), and NAOEs ($n = 585$). (3) WTA values are computed as $-\beta/\delta$ from the corresponding mixed-logit estimates; confidence intervals are constructed using the delta method following Hole [39]. (4) 1 mu $\approx$ 0.067 ha.

The comparison between Table 5 and Figure 2 reveals systematic operator-type differences along five dimensions. First, smallholders are simultaneously more inertial ($ASC = -4.67$ versus -3.30) and more compensation-responsive ($\delta = 0.018$ versus 0.013 , a 38% larger marginal utility per CNY), consistent with cash-constrained, risk-averse decision-making. Second, the intrinsic appeal of soil-testing-based fertilization is concentrated among NAOEs ($\beta = 0.395$, significant) and is statistically zero among smallholders, suggesting that the operational conditions making soil testing attractive (sufficient scale, variable-rate equipment, and extension integration) are unevenly distributed. Third, resistance to crop rotation is stronger among smallholders, who require roughly 30 CNY/mu more compensation than NAOEs (WTA 169 versus 139 CNY/mu), reflecting smallholders' higher transition costs and tighter dependence on the rice sales channel. Fourth, smallholders display a more pronounced income-subsidy preference: their WTA for switching from income subsidy to price subsidy is more than double that of NAOEs (55 versus 25 CNY/mu), reflecting more acute liquidity constraints. Fifth, within-group preference heterogeneity is uniformly larger among smallholders, with random-parameter standard deviations roughly 1.5 to 4 times those of the NAOE subsample across all eight random parameters, indicating that the classification into smallholders and NAOEs alone does not exhaust scope for differentiated compensation.

Two dimensions, by contrast, show comparable preferences across the two groups. The qualitative ranking of the five fertilizer-reduction measures is preserved in both subsamples (rotation requires the most compensation, organic substitution second, and soil testing the least), even as point estimates differ. The input subsidy form is similarly disliked relative to income subsidy in both groups (WTA ≈ 40 CNY/mu for smallholders and 37 CNY/mu for NAOEs).

4. Discussion

4.1. Preferences Across the Choice Attributes

The multi-binary-attribute design recovers practice-specific non-monetary preferences that vary qualitatively across the five reduction measures, reflecting operationally distinct mechanisms rather than a single underlying disutility of “reducing fertilizer.” Soil-testing-based fertilization is the only measure that respondents value intrinsically (negative WTA), reflecting its dual character as both fertilizer-reducing and cost-saving. By aligning input application with measured soil-nutrient deficiencies, the practice produces direct savings on fertilizer expenditure that compensate for the testing fee and effort, with adoption consistent with optimization rather than sacrifice. At the opposite end, organic substitution and crop rotation impose substantially larger non-monetary costs (WTA 93 and 152 CNY/mu) than their per-mu cost benchmarks would suggest, indicating that costs and risks fall outside the per-mu cost benchmark used in our design. Organic substitution involves sourcing, transporting, and applying bulky materials with delayed nutrient release and quality concerns, while crop rotation imposes cropping-system reorganization, market and equipment requirements for the rotation crop, and yield-trajectory uncertainty during transition. The strong income-subsidy preference (35–41 CNY/mu over price-subsidy and input-subsidy alternatives) reflects three behavioral channels operating jointly [42]: income transfers are unrestricted in use, so households can direct them to whatever need is most pressing rather than being tied to specific inputs; their transaction costs are lower than those of price-subsidy mechanisms, which require participation in particular marketing channels; and direct income transfers smooth household liquidity in a way that input transfers do not. Together, these patterns indicate that aggregating fertilizer reduction into a single attribute, as much of the prior CE literature does, conceals not only the rank ordering but the substantive mechanisms that should shape program design.

The remaining attributes are informative in different ways. The compensation coefficient is positive and highly significant ($\delta = 0.0150$, $p < 0.001$), confirming that tying compensation to a share of adoption cost identifies monetary preferences relative to that cost rather than to an arbitrary amount, a property that conventional CE designs with bundle-independent monetary amounts cannot deliver, and which makes the WTA estimates portable to programs in which subsidies are calibrated to implementation cost. By contrast, service-mode preferences (on-site field guidance versus centralized training) are not statistically distinguishable from zero, suggesting that respondents in our sample treat the two extension formats as broadly substitutable. The null result is itself informative: the form of technical-support delivery is unlikely to be a primary lever for shaping participation, and implementation-cost considerations may therefore reasonably dominate the choice between extension formats.

4.2. Heterogeneity by Farm-Operation Scale and Individual Characteristics

Smallholders are simultaneously more inertial and more compensation-responsive. The combination of stronger status-quo preference (ASC of -4.67 versus -3.30) and higher compensation marginal utility (δ of 0.018 versus 0.013 , a 38% larger marginal utility per CNY) means that smallholders are harder to mobilize from inaction but, once mobilized, respond more strongly to each additional CNY of compensation. This pattern is consistent with cash-constrained, risk-averse decision-making: the same household whose tight cash flow makes habitual practice “safe” also values the marginal CNY of payment more highly.

The two operator types also differ on specific measures. The intrinsic value of soil-testing-based fertilization is concentrated in NAOEs, whose non-monetary coefficient is significantly positive, while smallholders’ is statistically zero. The returns to soil testing scale with the area to which a single testing report applies, and integration with mechanical variable-rate application requires equipment more available at scale. Resistance to crop rotation, by contrast, is strongest among smallholders, whose WTA for rotation (169 CNY/mu) exceeds that of NAOEs (139 CNY/mu) by approximately 22%. Smaller cropping operations limit smallholders’ ability to absorb rotation-induced operational adjustments, given their more limited equipment access, marketing channels, and yield-variability buffers for the rotation crop.

Individual characteristics confirm familiar patterns. Older respondents prefer the status quo more strongly, while education and agricultural-income share are associated with greater openness to participation. The agricultural-income-share finding is noteworthy: respondents whose livelihood is more dominated by farming are more, not less, willing to participate, consistent with a skin-in-the-game mechanism in which farming-dependent households internalize long-term productivity benefits more fully than households with substantial off-farm buffers [21,23].

4.3. Policy Implications: From WTA to Compensation Design

The WTA estimates speak directly to the design of fertilizer-reduction compensation in Jiangsu and comparable settings. Existing Jiangsu support is largely measure-specific but calibrated against narrow cost benchmarks: mechanized straw return at 10 – 25 CNY/mu, ecological deep plowing at 40 CNY/mu [28], and organic substitution at approximately 100 CNY/mu under pilot programs of the Ministry of Agriculture and Rural Affairs [27]. Our point estimates (straw return 19 CNY/mu, deep placement statistically zero, organic substitution 93 CNY/mu) are broadly consistent with these existing flat rates, suggesting that current program rates are in the neighborhood of farmer mobilization thresholds for these lower-cost practices. This alignment should, however, be interpreted with appropriate caution: for straw return, the 90% confidence interval ($[5.24, 32.35]$ CNY/mu)

extends below the 10 CNY/mu lower bound of existing subsidies, so the mobilization threshold could lie somewhat beneath current rates, and the consistency we report is therefore indicative rather than precise. By contrast, crop rotation requires substantially higher compensation (152 CNY/mu) than is currently offered through any flat-rate program in Jiangsu, indicating that rotation is materially under-incentivized and unlikely to spread without meaningful payment increases or complementary risk-management instruments such as forward contracts and market guarantees for the rotation crop. For soil-testing-based fertilization, the negative WTA suggests that subsidies should focus on access (testing-fee underwriting and extension capacity) rather than adoption inducement.

Cost-share frameworks merit consideration alongside flat-rate structures. International cost-share programs, such as the U.S. Environmental Quality Incentives Program, which covers up to 75% of approved practice costs [29], have demonstrated administrative feasibility at large scale, consistent with the broader payments-for-environmental-services principle of aligning payments with provider opportunity costs [43]. Within China, related cost-share logic already operates in adjacent policy areas (agricultural-insurance premiums subsidized at central rates of 35% to 45% with additional provincial co-funding and machinery scrap-and-replacement support at up to 30% of market value) [44,45]. Our WTA estimates can be interpreted directly as implied minimum cost-share rates: 76% for crop rotation (152/200), 62% for organic substitution (93/150), and 63% for straw return (19/30). These are quantitative benchmarks for future program design under either flat-rate or cost-share structures.

Differentiated compensation by farmer type is justified. The comparison between smallholders and NAOEs reveals that uniform payment levels are unlikely to be efficient. For crop rotation, smallholder WTA exceeds NAOE WTA by approximately 30 CNY/mu, a 22% gap. This suggests that, relative to NAOEs, smallholders' participation responds more strongly to additional compensation than to non-monetary support, whereas for NAOEs, non-monetary measures (such as technical assistance) carry comparatively greater weight. Income-subsidy form is far more important to smallholders than to NAOEs, suggesting that program-design simplifications (input delivery for administrative ease) impose larger welfare costs on smallholder participants than on NAOEs. Consistent with the findings on individual characteristics, age- and education-targeted outreach in regions where the rural age structure is most skewed is likely to be a high-leverage complement to financial incentives.

The preference for income subsidies, although robust and statistically significant, is quantitatively secondary to the practice-specific payment gaps: the WTA for switching from an income to a price subsidy (35 CNY/mu in the full sample, 55 CNY/mu among smallholders) is modest compared to the WTA for crop rotation (152 and 169 CNY/mu). The first-order lever for program design is therefore the payment level for high-cost practices such as rotation, with the choice of subsidy form a second-order refinement.

4.4. Transferability of the Methodological Template

The two design choices made here are not specific to fertilizer reduction. The first represents each of the practices as its own binary attribute, so that a single policy alternative can bundle any subset of them; this captures the combinations of measures that farmers actually adopt together, rather than collapsing reduction into one aggregate attribute or a set of mutually exclusive options. The second ties compensation to that bundle, setting the payment as a share of the combined incremental adoption cost of whichever practices it contains. Both carry over to any agri-environmental payment program where producers genuinely combine several discrete practices rather than adopting a single one, and where a payment can be attached to the incremental cost of each practice.

European agri-environment-climate measures and eco-schemes are the clearest case. Farmers there enroll in self-chosen combinations of options: cover cropping, buffer strips, reduced tillage, and the upkeep of hedgerows and other landscape features. By regulation, the support is calculated to compensate the extra costs incurred and the income foregone. Our two features fit this setting closely: the binary-attribute structure delivers practice-specific WTA estimates that are comparable across sub-measures, and so usable for allocating a budget among them, while the cost-proportional payment matches the cost-based calculation these schemes already use. The United States Environmental Quality Incentives Program works on the same logic, with producers combining several conservation practices in a single cost-shared contract. The related Conservation Stewardship Program is only a partial fit: producers again assemble activities from a menu, but it pays for whole-operation conservation performance rather than for the cost of any individual practice. Domestically, China's cropland rotation-and-fallow pilots and conservation-tillage subsidies bundle discrete, separately costed practices in much the same way.

The approach has little to offer outside these conditions. Where a single practice is adopted in isolation, or where payments are fixed lump sums unrelated to cost, a conventional single-attribute design with one fixed monetary attribute remains adequate. Setting out the boundary in this way is what supports the claim, made in the Introduction and Conclusions, that the design is transferable well beyond the fertilizer setting.

5. Conclusions

Using a discrete choice experiment with two design innovations (multi-binary representation of five fertilizer-reduction measures and cost-proportional framing of compensation), this paper recovers practice-specific willingness-to-accept estimates from 1066 rice farmers in Jiangsu Province. The five measures generate distinct non-monetary preferences: soil-testing-based fertilization is intrinsically valued, deep placement is approximately neutral, and crop rotation requires substantially greater compensation than the others. Preference heterogeneity is significant on every random parameter; income subsidies dominate price-subsidy and input-subsidy alternatives; and smallholders are simultaneously more inertial and more compensation-sensitive than NAOEs, with materially higher rotation WTA and a stronger preference for income transfers. These findings carry direct policy implications: existing flat-rate subsidies approximate mobilization thresholds for low- and medium-cost practices but materially under-incentivize crop rotation, and both payment level and subsidy form merit differentiation by farmer type. Beyond the Chinese fertilizer setting, the methodological template (practice-specific WTA estimates on a cost-anchored monetary scale) is transferable to other agri-environmental contexts in which adoption is genuinely combinatorial. In sum, by representing each practice as a separate binary attribute and tying compensation to practice-specific adoption costs, this study provides differentiated, internally comparable willingness-to-accept estimates that can inform the cost-effective allocation of agri-environmental payments across both smallholders and NAOEs.

Several limitations qualify these conclusions and point to productive directions for future work. First, the WTA estimates rest on stated rather than revealed preferences; while the cheap-talk and budget reminders described in Section 2.2.3 help mitigate hypothetical bias, ex post validation against actual program take-up under future cost-share pilots would strengthen confidence in the magnitudes recovered. Second, the utility specification is additive across fertilizer-reduction measures and therefore does not model agonomic complementarities or substitutability between practices (for example, the joint adoption of straw return and organic substitution may carry both interactive cost-savings and overlapping nutrient-source effects); explicit modeling of measure interactions, alongside latent-class analyses within the smallholder and NAOE subsamples, are natural

extensions. Third, the sample is drawn from a single province; replication in other major Chinese rice-producing regions and in additional agro-climatic zones would be valuable for assessing the external validity of the magnitudes reported here, even as the methodological template itself extends straightforwardly across settings.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki. This non-interventional questionnaire survey was filed with and approved by the College of Economics and Management, Northwest A&F University before data collection (approval date: 2 September 2024; no formal approval/reference number was assigned). The College had not established a dedicated Institutional Review Board or Ethics Committee for this type of minimal-risk, anonymous questionnaire survey. The survey did not collect personally identifiable information, biological samples, medical/health data, images, or videos. Participants were informed of the study purpose, anonymity, data use, potential risks, and their right to refuse or terminate the survey at any time.

Informed Consent Statement: Verbal informed consent was obtained from all participants. Verbal consent was obtained rather than written because this was an anonymous, non-interventional, minimal-risk questionnaire survey, and written signatures would have created unnecessary identifiable records.

Data Availability Statement: The data presented in this study are available on request from the corresponding author due to privacy restrictions, as the dataset contains household-level survey responses from participating farmers.

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