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Do public works decrease farmers' soil degradation? Labour income and the use of fertilisers in India's semi-arid tropics

MARRIT VAN DEN BERG
Development Economics Group, Wageningen University.
Email: M.M.vandenBerg@kub.nl

ABSTRACT. This paper investigates the possibility of using public works to stimulate farmers' fertiliser use in India's SAT. Inadequate replenishment of removed nutrients and organic matter has reduced fertility and increased erosion rates. Fertiliser use, along with other complementary measures, can help reverse this process, which ultimately leads to poverty, hunger, and further environmental degradation. In a high-risk environment like India's SAT, there may be a strong relation between off-farm income and smallholder fertiliser use. Farmers can use the main source of off-farm income, wage income, to manage risk as well as to finance inputs. Consequently, the introduction of public works programmes in areas with high dry-season unemployment may affect fertiliser use. This study confirms the relevance of risk for decisions regarding fertiliser use in two Indian villages. Nevertheless, governments cannot use employment policies to stimulate fertiliser use. Public works even decrease fertiliser use in the survey setting.

1. Introduction

Sustainability has become an important subject on the political agenda since the 1980s. Many people have realized that we cannot sustain economic development if we do not maintain the services and quality of natural resources over time. Sustainable development, therefore, requires the utilization of renewable resources at rates less than or equal to the natural rate at which they can regenerate. Moreover, waste flows to the environment should be kept at or below the assimilative capacity of the environment. Agricultural research and policy in developed countries tends to stress the latter aspect. A major concern is the contamination of surface and groundwater from (in)organic fertilisers and pesticides (Parr *et al.*, 1990). This type of research has limited relevance for the developing world, where the use of chemical inputs is low except in the most productive regions. A sharp degradation of natural resources is the basic challenge to be met in this part of the world (for example Reardon, 1995, for the Sahel; and Randhawa and Abrol, 1990, for India).

Although several factors have contributed to soil degradation, inadequate replenishment of removed nutrients and organic matter has reduced fertility and increased erosion rates (Bumb and Baanante, 1996). Nutrient

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depletion in India has caused light degradation of 1.9 million hectares of land, moderate degradation of 10.3 million hectares, and severe degradation of 1.5 million hectares (Lynden and Oldeman, 1997). Declining soil quality on smallholder soils initiates a process that ultimately leads to poverty, hunger, and malnutrition, and further environmental degradation (Pinstrup-Anderson and Pandya-Lorch, 1994).

Fertiliser use, along with other complementary measures, can help reverse the downward spiral of environmental degradation in several ways (Bumb and Baanante, 1996). First, fertilisers can provide much-needed nutrients and hence increase crop yields and food production. Second, higher yields imply more biomass, which helps maintain soil organic matter and vegetative cover. Third, by increasing crop production in high-potential areas, fertiliser use can reduce the pressure to clear forests for crop production. In addition, fertiliser use can help reduce global warming by enhancing sequestration of carbon in soil organic matter.

Despite the country's impressive record of crop production, India's per-hectare use of fertilisers is among the lowest in the world. Overall, less than half of the nutrients removed with crop production were applied as chemical fertilisers in 1983 (Randhawa and Abrol, 1990). Fertiliser use doubled between 1983 and 1999, but this was accompanied by an increase in cereal production of 40 per cent, pulses of 15 per cent and of other crops by on average, 50 per cent (FAO, 1999). Moreover, the aggregate numbers obscure strong regional differences. Production growth has come about largely in irrigated agriculture, and the government is increasingly concerned about the exorbitant use of fertilisers in these areas. On the other hand, agriculture has developed little in rain-fed areas. Although 70 per cent of the country's gross cropped area is farmed under rain-fed conditions, dryland agriculture receives only 20 per cent of total fertiliser in 1983 (Randhawa and Abrol, 1990). What is more, a significant share of cultivated area does not receive any fertiliser at all. Application of animal manure and atmospheric deposits somewhat reduce the gap between nutrient removal and replenishment resulting from low fertiliser use, but not enough to prevent the depletion of large dryland areas.

The existing nutrient deficits will have an adverse effect on food security and resource conservation, unless additional efforts are made to promote higher levels of fertiliser use in an environmentally sound manner (Bumb and Baanante, 1996). In the near future, a significant increase in the use of organic fertilisers is not feasible in India's semi arid tropics (SAT). Farmers value manure highly but apply far less than they view as desirable, as fodder availability limits the number of livestock that can be kept. Moreover, biomass scarcity makes the economics of mulching and green manuring in dryland agriculture decidedly unattractive (Walker and Ryan, 1990).

The effective promotion of fertiliser use requires clear insights in the determinants of input use at the farm level. Macroeconomic factors, such as the exchange rate, foreign exchange availability and inflationary pressures are important, but cannot explain differences in fertiliser application between neighbours or even regions. To explain these, we need to look into the farmers' microeconomic environment. For India's SAT, major fea-

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tures are the large variability of crop yields, the limited development of (especially long-term) financial markets and the importance of wage income for smallholder livelihood.

Wage income may have a strong impact on crop production in general and fertiliser use in particular. Households can use wage income to purchase fertilisers if they are unable or unwilling to take production loans (Reardon *et al*., 1994). Moreover, wage income may help reduce the variance of overall household income and improve food security by allowing the household to buy food in cases of yield shortfalls (Reardon, 1997). Households earning much wage income may, therefore, increase the riskiness (and profitability) of their agricultural activities. Depending on the relation between fertiliser use and production risk, this will lead to either an increase or a decrease in fertiliser use (Hanus and Schoop, 1989).

The above indicates that rural employment policies can lead to changes in smallholder fertiliser use. Village labour markets are reasonably competitive and responsive to the forces of supply and demand (Walker and Ryan, 1990). Nevertheless, in some areas unemployment rates are relatively high during the slack season. Employment policies could stimulate the use of inorganic fertilisers in these areas, provided that wage income increases fertiliser use.

Despite the potential importance of wages and other sources of off-farm income for agricultural decisions, few researchers cover this topic. Nonfarm income is sometimes included as an explanatory variable in regressions of farm decisions (for example Savadogo, Reardon, and Pietola, 1994). However, this does not shed light on the workings of the underlying decisions and constraints. Off-farm income is an integral part of the household's decision-making process, which concerns all income generating activities and consumption (De Janvry, 1994). Only within this context, can we expect to reveal the impact of off-farm income on fertiliser use. Hence, this paper develops an analytical model that shows the rationale behind household decisions regarding labour allocation and fertiliser use under risk and credit constraints. Contrary to previous research, the empirical analysis allows distinction between the effects of risk and credit constraints.

The structure of the paper is as follows. Section 2 elaborates on the problem of soil mining and describes the interaction between risk, credit, and fertiliser use in India's SAT. Section 3 introduces an analytical model of farm–household decision making. The model elucidates the relations described in section 2 and shows the potential effects of labour income on fertiliser use. In section 4, we examine empirical estimates of the determinants of household-level fertiliser use for two villages representing distinct agroecological and policy regions in India's SAT. Section 5 presents policy recommendations and concludes.

2. Fertiliser use in India's SAT

2.1. Fertiliser use and sustainability

A recent survey on human-induced soil degradation reports that erosion and depletion of plant nutrients is slowly reducing about 80 per cent of the cultivated land in the SAT to unproductive, parched terrain (Lynden and

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Oldeman, 1997). The magnitude of soil mining in rainfed agriculture is huge. Estimates of average nutrient removal are as high as 200 kg of *N*, 30 kg of *P* and 150 kg of *K* per hectare during the last decade (NRMP, 2000b). In many areas the situation has reached the point where production gains cannot be achieved without substantial increase in inputs. Nevertheless, farmers rarely perceive erosion and soil depletion as a high-priority problem. The losses in current productivity are low and can be masked by increased levels of inputs. Still, the losses are alarming in the long run or on a large area basis (Koala, 1999). Counteracting nutrient depletion requires an integrated approach including the use of organic as well as mineral fertilisers.

Out of concern for the limited sustainability of current production systems, the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) has initiated several projects focussing on improved nutrient management. A region that gets special attention is Mahbubnagar district, which is representative of rainfall-unassured red soil (alfisol) areas. The district has degraded soils with low fertility, and the main nutrient constraint is nitrogen (NRMP, 2000a). Other regions that get special attention are those areas with medium-textured black soils (vertic inceptisols). These areas are prone to severe degradation. Major constraints to crop production on these soils are soil erosion and depletion of nutrients.

In the empirical analysis, we use data from two villages: Aurepalle in Mahbubnagar district, which represents red-soil areas; and Kanzara in Akola district, which represents medium-textured black-soil areas. In both villages, the use of inorganic fertilisers is low but increasing (see figures 1a and b). Fertiliser use was more widespread in Kanzara than in Aurepalle. Especially in the latter village, farmers have applied fertilisers disproportionately to irrigated area. The picture is changing, as more and more farmers apply fertilisers on their dryland crops. Nevertheless, some dryland fields remain unfertilised and the amount of nutrients applied on fertilised fields is low. Tentative nitrogen balances for the major crops and crop mixtures in the two study villages indicate that nutrient removal is at least as high as the SAT averages presented above (see table 1).

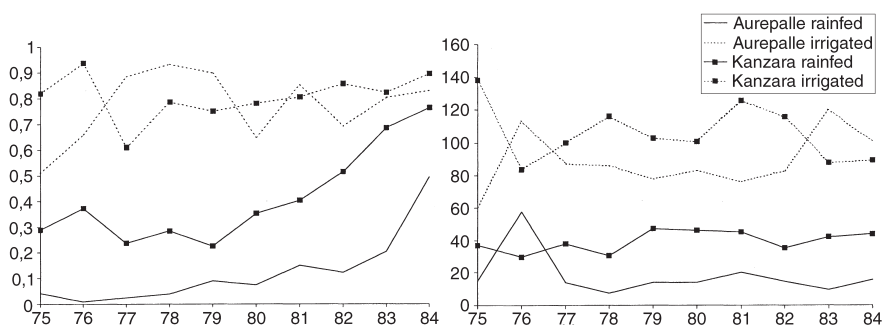


Figure 1. *Spread of fertiliser use in two villages in India's SAT, 1975–1984*
(a) share of fertilised fields; (b) kg nutrients/ha on fertilised fields

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Table 1. *Tentative nitrogen balances for the study villages (kg/ha)*

	Aurepalle		*Kanzara*	
	Sorghum/pearl millet/pigeon pea	*Castor*	*Hybrid sorghum*	*Cotton/pigeon pea/local sorghum*
Nitrogen additions				
manure	0	0	0	0
fertiliser	0	0	15	0
biological *N* fixation	3	0	0	5
atmospheric deposition	5	5	5	5
Nitrogen losses				
removal with crop	24	18	63	23
leaching	5	5	7	4
volatilization	10	10	15	10
Balance	−31	−28	−65	−27

Sources: Dev (1994), NRMP (2000a), Pol (1992), Walker and Ryan (1990).

2.2. Fertiliser use in a high risk environment

Perhaps the most influential characteristic of India's SAT is the high variability of rainfall. The resulting yield uncertainty is the main source of income risk for farm households (Walker and Ryan, 1990). Ideally, farmers would use intertemporal markets to shield consumption from variations in income. In reality, informational asymmetries and covariance of risk impede the development of markets for insurance and long-term credit, and the consumption-smoothing capacity of farm households is limited (Townsend, 1994). Consequently, farmers will try to restrict risk exposure to shocks that can be handled with the means available.

One way to limit income variability is through adaptations in input use: inputs affect not only the level of output, but also its variability (Just and Pope, 1979). The relation between fertiliser use and the riskiness of crop production is ambiguous and depends on the specific environment, crop and technology. Some researchers do not find significant effects of fertiliser intensity on yield variability (for example, Smale *et al*. (1998) and Traxler *et al*. (1995) for wheat in the Punjab of Pakistan and Mexico, respectively). On the other hand, Hanus (1989) concludes that nitrogen applications at the beginning of growth reduce the variability of wheat and barley yields, while applications at later stages increase yield variability. Besides timing, the level of technology shapes the relation between nitrogen and yield variability, as two studies on Philippine rice cultivation illustrate. In the humid and semi-humid areas of the Philippines, nitrogen is risk reducing for modern rice varieties under careful management (Antle and Crissman, 1990), but moderately risk increasing under average conditions (Roumasset, 1989). Hence, whether fertiliser increases or decreases yield variability is essentially an empirical matter that may well vary considerably from site to site (Hanus and Schoop, 1989). It is, for example, not possible to extrapolate results from the humid and semi-humid tropics to dryer areas, as the frequent occurrence of moisture stress could interact with nitrogen to produce greater yield variability with nitrogen application (Smith and Umali, 1985).

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Farmers risk perceptions, moreover, do not necessarily coincide with the technical effect of fertilisers on yield variability. Empirical evidence indicates that fertilisers increase the yield variability of sorghum yields in the USA. Nevertheless, SriRamaratnam *et al.* (1987) found that ten out of 12 Texas sorghum producers considered nitrogen fertiliser to be risk reducing. Consequently, typical US farmers apply more nitrogen than the profit-maximizing level (Babcock, 1992). This is rational, if *ex post* optimal fertiliser rates are positively correlated with yield.[1] In this case, fertilising for average conditions leads to relatively high levels of foregone income in good years, while the costs of some additional fertilisers in normal years are relatively low (Babcock and Blackmer, 1994). Uncertainty about the availability of nitrogen in the soil can also explain the observed high levels of nitrogen application. If the marginal product of nitrogen is a convex function, increasing uncertainty about the availability of soil nitrogen will increase nitrogen application. This is true for many continuous functions, such as the Cobb–Douglas, and for those that contain a plateau (Babcock, 1992). The intuition of this result is that increasing nitrogen usage above the amount that is needed on average imposes less loss when soil nitrogen is abundant than the gain when soil nitrogen is deficient.[2]

2.3. Labour income and fertiliser use

Adaptations in input use are not the only possible strategy for income stabilization: farmers can also diversify their income off-farm. In rural areas of India's SAT, the major source of income besides crop production is the labour market. Income earned in this market has a potentially strong impact on risk: early season income may serve as a certain consumption floor (*ex ante* risk management), while end-of-season income can be used to compensate for actual yield losses (*ex post* risk coping).

Labour income can also provide a substitute for short-term credit for farmers who are not able or willing to obtain a production loan. Contrary to the compelling evidence on the limited availability of consumption-smoothing credit, empirical evidence on the adequacy of short-term production credit is mixed. Several studies indicate that most smallholders have some access to short-term formal loans. A study in three SAT villages between 1975 and 1984 shows that the only farm households systematically excluded from institutional credit are the rare households headed by widows (Walker and Ryan, 1990). Studies from other parts of India present a similar picture: for example 74 per cent of all households that want a formal loan can get one in the economically diverse state of Uttar Pradesh (Kochar, 1997b). Moreover, access to formal or informal credit does not affect land rental decisions in that state (Kochar, 1997a). According to Kochar, this suggests that lack of access to credit does not constrain households in their working capital requirements. He, therefore, concludes the

[1] This condition holds if fertiliser is inexpensive relative to its marginal value in production when less-than-optimal rates are applied.

[2] The farmers in the study area are likely to have imprecise knowledge about the level of fertiliser deficiency, and hence not know the exact optimal level of fertiliser application.

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following: 'the finding … suggests that credit constraints cannot explain levels of input use'. However, credit constraints may affect input intensity even if they do not influence the size of the cultivated area. All-India district-level data indicate that this may be the case for Indian smallholders: the availability of formal credit, as measured by the availability of credit institutions, is an important determinant of agricultural input use (Binswanger and Khandker, 1993).

The use of wage income to manage risk and liquidity requires buoyant labour markets. In India's SAT, the bulk of labour is traded in the daily rated labour market, which is flexible and impersonal in nature. Linkages with the markets for land and credit are the exception rather than the rule. Nevertheless, in some areas there is excess supply of labour during the dry season. Previous research shows that this limits the use of labour markets to stabilize total income (van den Berg, 2000). A comparison between two villages indicates that households adjust labour supply to realized yields only in the village having a year-round public works programme. In the other village, limited dry-season employment possibilities prevent households from using this strategy. By way of compensation, they work longer hours in the growing season in order to create a buffer for yield risk.

3. A simple farm household model

This section develops an analytical model that describes potential relations between risk, credit constraints, labour income, and fertiliser use. The model covers a single agricultural year, as farmers have only limited capacity to smooth consumption between years. We assume that labour markets are perfect: labour can be hired in and out at a single wage rate at all desired levels. This allows us to show the potential impact of wage income on fertiliser use. In the next sections, we consider the consequences of dry-season unemployment and the effects of employment-generating policies on fertiliser use.

The model starts from a whole-farm production function. In the planting and growing season, the household allocates labour (L_1) and inorganic fertilisers (I) to plant and grow a crop on a given acreage (A). At this moment, the future output is uncertain due to exogenous stochastic factors, such as weather and pest infestation (ϵ). The impact of possible shocks on crop yields depends not only on the quality of the farmer's land (γ) but also on the level of inputs

$$Q = f(A,L_1,I) + h(A,L_1,I)\gamma\varepsilon,\ \varepsilon \sim N(0,1) \tag{1}$$

The equation is formulated such that $E(Q) = f(A,L_1,I)$ and $\mathrm{Var}(Q) = (h(A,L_1,I)\gamma)^2$. This way, the effects on mean and variance of output can be independent.[3] Q_V (the marginal product of variable input V = L_1,I) is always positive, while h_V (the marginal risk effect of an input) is positive

[3] We feel that the assumption of normality is a good enough approximation of reality, as Walker and Ryan (1990) conclude that most improved cropping systems and traditional intercrops are characterized by normal yield distributions in the two study villages. Besides, our empirical estimates account for the farmers' risk perception of an input, and not its effect on yield variability.

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for risk-increasing inputs and negative for risk-decreasing inputs (Just and Pope, 1979).

We assume a linear harvest-stage production function. In other words: the total labour required in harvesting operations (L_2) is proportional to the harvested crop (Saha, 1994)

$$L_2 = \alpha Q \tag{2}$$

where α is some positive constant.

Besides, through crop production, the household can generate income through wage employment. Labour can be hired in and out freely at a single wage rate (w). While in India's SAT the availability of long-term credit is limited, an extensive network of co-operatives and informal lenders provide short-term production credit. The model, therefore, allows for borrowing in the planting stage (B). All loans must be repaid at harvesting at interest rate r, and there is a maximum amount that a household can borrow (B_m). The size of this amount depends on the characteristics of the household (Z). Hence, the budget constraints are

$$C_1 = w_1(F_1 - L_1) + B \tag{3}$$

$$C_2 = p(f(A,L_1,I) + h(A,L_1,I)\gamma\varepsilon) + w_2(F_2 - L_2) - (1 + r)B \tag{4}$$

$$B \leq B_m(Z) \tag{5}$$

where p denotes the output price. L is the sum of family and hired labour in farm production, while F is the household's total labour supply, that is the sum of on-farm and off-farm family labour.

The difference between each period's total time endowment (T) and family labour supply (F) equals home time (ℓ)

$$\ell_t = T_t - F_t \; t = 1,2 \tag{6}$$

The household facing these constraints maximizes the utility (U) of consumption (C) and leisure (ℓ) in both stages. Households are risk-averse and prudent, and the precise form of the utility function depends on the household's characteristics (Z). The household decision variables are family labour supply (F) and labour use (L) in both stages, and borrowing (B) in the planting stage.

The above implies that the harvest-stage decision problem is

$$W = \underset{F_2}{\text{Max}} U(C_2,|_2;Z) \; U_i > 0; \; U_{ii} \; 0; \; U_{iii} > 0; \; i = C,| \tag{7}$$

subject to

$$C_2 = (p - \alpha w_2)Q^* + w_2F_2 - (1 + r)B^* \tag{8}$$

$$\ell_2 = T_2 - F_2 \tag{9}$$

where B^* and Q^* are predetermined, and p, T_2, w_2, and r are given. Hence, household decisions regarding B, L_1 and I affect F_2, either directly or through their impact on crop output.

Substituting equations (8) and (9) into equation (7) gives

$$W = \underset{F_2}{\text{Max}} U((p - \alpha w_2)Q^* + w_2F_2 - (1 + r)B^*,T_2 = |_2;Z \tag{10}$$

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The first-order condition is

$$U_{\ell_2} = \varphi_2 U_{C_2} \tag{11}$$

This is the standard condition for consumer utility maximization. Given the level of full income, the household chooses between the consumption of goods and leisure. When crop profits (and consequently full income) are low, the household can increase labour supply in order to smooth income *ex post*.

Hence, the planting-stage decision problem is

$$V = \underset{L_1,F_1,B}{\text{Max}}(U(C_1,\ell_1;Z) + \rho EW(Q_1^*,B^*))\ U_i > 0;\ U_{ii} < 0;\ i = C,\ell \tag{12}$$

subject to

$$C_1 = w_1(F_1 - L_1) + B \tag{13}$$

$$B \leq B_m(Z) \tag{14}$$

$$\ell_1 = T_1 - F_1 \tag{15}$$

where ρ is the intertemporal discount factor, and E denotes expectation.

The Lagrangian for this problem is

$$\begin{aligned}\Im = {} & U[w_1(F_1 - L_1) + B,T_1 - F_1] + \rho EU[(\rho - \alpha w_2)(f(A,L_1,I) \\ & + h(A,L_1,I)\gamma\varepsilon) + w_2F_2 - (1 + r)B,T_2 - F_2;Z] + \lambda(B_m - B)\end{aligned} \tag{16}$$

which we get through inserting equations (13), (15), (10) and (1) into equation (12). Moreover, the Lagrangian multiplier λ accounts for the borrowing constraint (equation (14)).

The four decision variables are L_1, I, B, and F_1. Recall that the choice of L_1, I, and B affects harvest-stage decisions regarding F_2. Moreover, the stochastic stock (ε) affects Q and thus L_2 and F_2. Hence, Q, L_2, and F_2 are uncertain in the planting stage. We can now derive the planting-stage Kuhn–Tucker conditions (see appendix)

$$U_{\ell 1} = w_1 U_{C1} \tag{17}$$

$$f_v = \frac{p_V}{p - \alpha w_2}\frac{U_C}{\rho EU_{C_2}} - h_V\gamma\frac{E(U_{C_2}\varepsilon)}{EU_{C_2}} \tag{18}$$

$$U_{C_1} = \rho(1 + r)EU_{C_2} + \lambda \tag{19}$$

$$\lambda \geq 0 \tag{20}$$

$$B \leq B_m(Z) \tag{21}$$

where $\lambda > 0$ if $B = B_m$, and p_V is the price for variable input V (w_1 for L_1 and p_i for I). Note that equation (18) represents the first-order conditions for both variable inputs: labour and fertilisers. Combining equations (18) and (19) gives

$$f_V = \frac{1 + r}{p - \alpha w_2}p_V + \frac{\lambda}{\rho(p - \alpha w_2)EU_{C_2}} - h_V\gamma\frac{E(U_{C_2}\varepsilon)}{EU_{C_2}} \tag{22}$$

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Equation (22) demonstrates the impact of risk and credit constraints on the use of inputs in crop production. First, consider the impact of risk. Risk causes non-separability of production and consumption decisions. Consequently, the value of the marginal product of an input is not equal to the discounted price even after correcting for harvesting costs (αw_2). The difference is a correction factor that covers the joint effect of household risk preferences and the marginal risk effect of the input. The sign of this correction factor is ambiguous and depends on the sign of the marginal risk effect of the input at hand.

In the presence of credit constraints, the household may not be able to attain maximum expected utility as described in the previous paragraph. If credit demand exceeds the availability of credit, the household will take the maximum loan available and allocate resources and consumption accordingly. Hence, the household will consume less and use less inputs than it would in the absence of a credit constraint. Whether or not credit constraints are binding depends not only on the availability of credit and on objective factors such as land size and production risk, but also on household preferences. Prudence, for example, may limit borrowing, because farmers want to avoid repayment requirements after a bad harvest.

Risk and credit constraints induce farmers to decide simultaneously on input use and family labour supply (equation 17). Hence, potential labour income, as measured by the family labour endowment, will influence the use of fertiliser. Several possible effects are easily understood intuitively. Planting-stage labour income is secure, even if crops fail. This lowers the disutility associated with yield loss. Besides, farmers can use labour income to compensate for crop income losses by increasing labour supply after (and during) a bad harvest. Finally, labour income increases household liquidity and the capacity to self-finance fertiliser use.

4. Farmers' fertiliser use

The above model shows that many factors affect fertiliser use in the presence of risk and credit constraints. Farmers not only account for relative prices and the available resources and technology, but also for, for example, the riskiness of production, the possibility to maintain acceptable levels of consumption after a bad harvest, and the availability and price of short-term credit or other sources of liquidity. This leads to the following decision rule for fertiliser use

$$\frac{I}{A} = F(A,p,w_1,w_2,p_i,r,\gamma,T_1,T_2,\rho,Z) \tag{23}$$

This equation is part of an integrated set of household decisions regarding income generation and risk management. Focussing on just fertiliser use may somewhat limit the efficiency of the estimates, but does not bias the results.

For empirical estimation of the above reduced-form equation, we used data from two Indian villages for the period 1975–1984: Kanzara and Aurepalle. The data were collected by resident investigators from ICRISAT. With three-to-four-week intervals the investigators collected

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data on household transactions, labour and draught power utilization, and crop cultivation. Annually, they updated information on the composition of the household and asset ownership (Walker and Ryan, 1990).

The villages represent different biophysical and socio-economic regions of India's SAT. Major differences relate to the productivity and riskiness of crop production and the households' capacity to use labour markets to manage risk. Both the average productivity of agriculture and the stability of yields are lower in drought-prone Aurepalle than in rainfall-assured Kanzara (see section 2.1). Farmers in both villages use labour market participation to stabilize income. In Kanzara, a public-works programme provides year-around employment. This allows households to increase labour supply when yields are low. High dry-season unemployment inhibits the use of this strategy in Aurepalle. However, farmers in this village work longer hours in the planting season if they face higher production risks (van den Berg, 2000).

The above indicates that income variability is highest in Aurepalle for two reasons: (i) higher yield risks; (ii) limited possibility to use the labour market for income smoothing. This high variability of income may not be a problem, because the largely informal village financial market favours the use of credit for consumption smoothing: 75 per cent of the income-shortfall households were net borrowers. This contrasts Kanzara, where formal credit has replaced informal loans, and borrowing did not increase in low-income years. Nevertheless, the (limited) availability of consumption-smoothing credit did not prevent Aurepalle households from facing a higher variability of consumption than their compatriots in Kanzara face.

4.1. Estimation issues

In order to account for the above-mentioned inter-village differences, we estimate separate fertiliser functions for Aurepalle and Kanzara. We use data on the application of the most frequently utilized nutrient: nitrogen. As only some of the farmers apply nitrogen, we could use either Tobit or a combination of Probit and truncated regression. We have selected the second option, for tests strongly reject equality of the effects of the independent variables on the decision to use fertilisers and the quantity of fertilisers used. The reported variance estimators are robust for the panel nature of the data: the estimation method does not assume independence of the observations for a single household. This is important, since some farmers may possess higher-quality soils than others, either through inherent qualities of their land or through continuous investment in soil quality.

The estimated fertiliser functions cover irrigated as well as dryland production. Estimation of the level of nitrogen use in dryland production was not possible for Aurepalle farmers: the resulting number of cases is too small to run a sensible truncated regression. For the other equations, the estimates for dryland alone are similar to those for total cultivated area. Only the latter are presented below.

We calculate the 'riskiness' of crop production (γ) using the two-stage method outlined by Just and Pope (1979). Just and Pope define a composite production function which is the sum of two functions—a

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regular production function specifying the effects of inputs on the mean of output; and a function specifying the effects of inputs on output variance (see also equation (1)). Step one covers the estimation of the regular production function. The residuals of this regression are estimates of the standard deviation of output. Step two involves regression of these residuals on the input variables. The resulting equation serves to compute the standard deviations of crop production for each farmer. As we need a measure of *ex ante* risk, we do not use conventional inputs in our regression. Instead, we regressed output on cultivated area, share of irrigation, land value, a time trend, and some proxies for the farmer's weather information: the share of crops for which the adoption is known to be sensitive to expectations of weather (Kochar, 1999).

The set of household characteristics (Z) is specified such that it covers proxies for the household's risk aversion and its access to credit and alternative sources of liquidity. We include the value of liquid assets,[4] the size of area owned and the value of livestock in the equation. Liquid assets and livestock income are alternatives to credit, while land ownership serves as collateral. Moreover, asset endowments serve as proxies for risk aversion: wealthier households have more possibilities to smooth consumption between years. These smoothing options are more important for risk behaviour than pure risk preferences (for example, Rosenzweig and Binswanger, 1993). Besides, we add a number of other proxies for household preferences and farming skills: the age of the household head, caste, the number of literate household members, and the number of household members with secondary education (see table 2).

In order to detect non-linearities in the relation between risk, asset ownership, and fertiliser use, we included interaction terms and quadratic variables in a first regression. Only the interaction term between risk and liquid assets appeared influential and was retained in the final regression. Moreover, we included a quadratic term for cultivated area in the Kanzara equations. In the case of Aurepalle, inclusion of such a term only decreased the significance of the effect of cultivated area.

All prices used are village averages. There are four relevant wage rates: the planting and harvest wage for male and female labour, which farmers consider as separate inputs. However, these wage rates are highly correlated, and we include only female planting wage rates to prevent multicollinearity. We ignore the interest rate, as data availability is limited and village averages appear to be stable. Since animal traction is a third important input besides labour and fertilisers, we incorporate bullock hiring prices and a dummy for bullock ownership to account for possible hiring restrictions. Other additional variables are a time trend and the share of irrigated area.

4.2. Results

Our estimation results give a clear impression of the effects of risk, short-term credit constraints, and family labour on the use of fertilisers in the two study villages (see table 3). Risk strongly affects the use of fertiliser,

[4] Hausman tests do not reject exogeneity of this variable.

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Table 2. *Descriptive statistics of the survey households (1976–1984)*

	Aurepalle (N = 258)		*Kanzara (N = 255)*	
	Mean	*Standard dev.*	*Mean*	*Standard dev.*
Inorganic nitrogen use				
nitrogen intensity (kg/ha)	5.29	10.31	11.49	14.43
nitrogen for users (kg/ha)	12.16	12.70	17.48	14.57
% of cases with nitrogen > 0	0.43	0.50	0.65	0.48
Agricultural Resources				
cultivated area (ha)	3.37	2.88	5.74	7.03
irrigated area/total area	0.10	0.17	0.03	0.11
'riskiness' of crop production	1,785.41	1,516.60	2,811.31	2,922.91
bullock owned (yes = 1)	0.60	0.49	0.56	0.50
Prices				
female planting wage rate (Rs/hr)	0.60	0.25	0.65	0.12
bullock price (Rs/hr)	1.40	0.20	2.23	0.28
nitrogen price (Rs/kg)	5.99	0.54	6.82	1.11
Skills				
farm caste (yes = 1)	0.35	0.48	0.45	0.50
age household head	53.62	12.49	43.78	9.61
number of literate adults	1.30	1.94	2.40	1.96
adults with secondary education	0.37	0.84	0.59	1.17
Assets				
liquid assets (Rs)	4,730.40	7,859.29	6,143.32	11,659.71
owned land (ha)	49,182.01	72,926.08	34,833.73	47,750.06
livestock ownership (Rs)	4,254.94	4,399.02	2,040.74	2,514.29
Labour endowment				
adults	3.76	1.62	4.19	2.17

Note: all monetary values are in 1983 prices.

Table 3. *Estimates of nitrogen intensity in two villages in India's SAT ('76–'84)*

	Aurepalle		*Kanzara*	
	Probit (N = 258)	*Truncated (N = 113)*	*Probit (N = 255)*	*Truncated (N = 162)*
Agricultural resources				
cultivated area (ha)	0.55003***	−1.39279**	0.48587**	−4.84526***
	(0.21113)[a]	(0.53886)	(0.22368)	(1.36674)
cultivated area squared	−0.02120*		−0.00125*	0.09126**
	(0.01131)		(0.00522)	(0.02635)
irrigated area/total area	15.0571***	22.9887	1.27815	7.38357
	(3.56028)	(16.7270)	(1.94908)	(8.03022)
expected yield (Rs/ha)	−0.00094	0.00345	0.00049**	0.00541**
	(0.00076)	(0.00360)	(0.00023)	(0.00237)
'riskiness' production	−0.00010	0.00328**	−0.00055	0.00592***
	(0.00044)	(0.00163)	(0.00039)	(0.00172)
bullock owned (yes = 1)	0.82394**	4.17901	0.03435	−6.33965**
	(0.37040)	(2.65223)	(0.31512)	(2.80163)
Prices[b]				
wage rate (Rs/hr)	−0.38589	89.5722	−1.08924	−7.65913
	(4.04973)	(56.9369)	(3.12701)	(17.7017)
bullock price (Rs/hr)	−1.41675	−7.84415**	−3.70074***	1.88930
	(1.11206)	(3.43747)	(0.99380)	(12.5448)
nitrogen price (Rs/kg)	−0.71183**	7.02686	0.50856	−2.91154
	(0.32176)	(6.23883)	(0.31040)	(2.35553)
Skills				
age household head	0.04091***	−0.19428*	−0.00919	0.37828***
	(0.01415)	(0.10342)	(0.01392)	(0.12248)
number of literate adults	0.32469	1.02578	−0.06879	0.39797
	(0.24209)	(0.99589)	(0.15008)	(1.00813)
adults with secondary education	−0.34086	−1.75607*	0.13989	−1.47197
	(0.28794)	(0.89532)	(0.24840)	(1.22094)
farm caste (yes = 1)	1.00632	3.55968	0.89143***	5.23487*
	(0.64840)	(3.64464)	(0.23083)	(2.93350)
Assets				
liquid assets (1,000 Rs)	−0.20163*	−0.03127	−0.13240**	0.75138**
	(0.11371)	(0.15143)	(0.05267)	(0.35074)
liquid assets (1,000 Rs) × riskiness	0.00016**	−0.00003	0.00008***	−0.00008*
	(0.00006)	(0.00004)	(0.00003)	(0.00004)
owned land (ha)	−0.12588***	0.06500	0.02499	0.06053
	(0.03248)	(0.13509)	(0.05865)	(0.22446)
livestock ownership (1,000 Rs)	0.01973	0.37750	−0.01101	1.14427
	(0.03689)	(0.14038)	(0.22767)	(0.78507)
Labour endowment				
adults	−0.32274*	−0.32654	−0.04992	−1.39981**
	(0.16819)	(0.91345)	(0.08872)	(0.61008)
Other				
year	0.32937	−4.53887	−0.11126	2.33781**
	(0.21629)	(3.17474	(0.10326)	(1.16531)
constant	−25.2195	366.519	13.7842	−164.896
	(15.3211)	(284.554)	(9.20742)	(114.337)
σ		5.30984***		8.94060***
		(0.61320)		(0.86450)
Wald χ^2	173.52	7,414.37	287.01	771.86
pseudo R^2	0.67		0.36	

Notes:
[a] Standard errors in parentheses. Standard errors are robust for within household dependence of observations.
[b] Previous year output prices for the major crops are included in the regression but not in the table: paddy and castor in Aurepalle, cotton in Kanzara, pigeon pea and sorghum in both villages.

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while the impact of credit constraints appears to be negligible. Despite the importance of risk for fertiliser use and the potential use of family labour to manage risk, increased fertiliser use is not a by-product of policies enhancing employment. On the contrary, a decrease in unemployment will even lead to a decrease in fertiliser use. The rest of this section elaborates on these and other results of the regression.

In both villages farmers increase the amount of nitrogen applied in response to risk. This coincides with the behaviour of US farmers as described in section 2. On the other hand, risk does not directly affect the probability of nitrogen use. The effect of risk on nitrogen levels is highest in Kanzara, where fertiliser use is more widespread: the risk elasticity of nitrogen intensity is 0.7 for Aurepalle and 1.2 for Kanzara.[5]

The coefficients for landownership reflect the inter-village difference in the availability of consumption-smoothing credit. In Aurepalle, households increase borrowing in low-income years. Large landowners have more collateral and can borrow more. Hence, they can take more risk in crop production and feel less need to use fertilisers to decrease risk. Consequently, the coefficient for land ownership is significantly negative in the Aurepalle probit equation. Land ownership does not affect fertiliser use in Kanzara, where consumption smoothing credit is virtually absent.

The above indicates that the availability of production credit does limit fertiliser use in the study villages. Land ownership increases loan access and would positively affect fertiliser use if credit were constrained. The absence of credit constraints is consistent with Kochar's assertion that working capital does not constrain agricultural production, as credit constraints do not affect land rental decisions. The results of Binswanger and Khandker, which show that the availability of credit institutions increases district-level fertiliser use, may be less relevant for our study villages: there is a credit co-operative in either village.

In Kanzara, liquid assets increase the use of risk-decreasing fertilisers, just like they decrease the use of stabilizing male labour. This reflects prudence: households prefer spending their own funds to taking a loan, which they must repay even when yields are low. The positive effect of liquid assets decreases at high levels of risk. On the other hand, the impact of liquid assets on the probability of fertiliser use is negative in both villages, and reflects the importance of liquid assets for consumption smoothing. Also this effect decreases with the level of risk.

The significantly negative impact of the number of adults for the probability of fertiliser use in Aurepalle and the level of fertiliser use in Kanzara confirms the important role of family labour in risk management. Households are less inclined to adapt fertiliser use to manage risk if they can use their labour endowment to cope with production risk. In Kanzara, the amount of fertiliser used decreases by 1.4 kg/ha in response to an additional family member, while in Aurepalle an additional family member increases the probability of fertiliser uses by 5 per cent. The latter effect is small: it would induce only two of the 144 predicted users of fertilisers not to use fertilisers anymore. It is not surprising that the impact of

[5] These elasticities are computed at village means for fertiliser users.

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family labour is largest in Kanzara. Households in this village have more possibilities to use the labour market to manage risk.

The remaining results do not directly relate to risk and liquidity constraints, but present other interesting insights into the determinants of fertiliser use. Input prices have only a limited impact on fertiliser use. The own-price elasticity is negative for the Aurepalle probit equation but not significantly different from zero in the other equations. The wage elasticity is insignificant in all four equations. On the other hand, the price elasticities for bullocks are negative. This indicates that animal traction and inorganic nitrogen are complements: crops benefit more from fertilisers in a well-worked soil. Although the negative coefficient for bullock ownership in Kanzara is puzzling, the opposite coefficient in the Aurepalle probit equation confirms the complementarity of animal traction and fertilisers.

Our estimates confirm the presence of an exogenous positive time trend in the level of nitrogen use in Kanzara. Both the probability of fertilisation and the level of nitrogen have increased in Kanzara. Surprisingly, the regressions do not pick up the strong upward trend in the probability of fertiliser use in Aurepalle that seems apparent from 1: the time trend in this specific equation is positive but only significant at the 15 per cent level or higher. Besides, the probability of fertiliser use increases with cultivated area, while the nitrogen intensity decreases with the area size in both villages. These effects level off for very large farms.

As expected, irrigation is an important determinant of fertiliser use in Aurepalle. The irrigation coefficients are positive in all equations, but only significant in the probability equation for Aurepalle. These results are in line with the observation that in both villages irrigated area has laid claim to a relatively large share of fertilisers, but that in Kanzara dryland crops also receive an appreciable amount.

Finally, household skills have a significant impact on fertiliser use. The age of the household head increases the level of nitrogen used in Kanzara and the probability of nitrogen use in Aurepalle. Nevertheless, older farmers apply smaller quantities of nitrogen than their younger colleagues do. Their experience induces them to use fertilisers, but only in small quantities. The farm caste dummy also reflects the importance of farming skills for fertiliser use. Kanzara households from traditional farming castes are more likely to use fertilisers and apply larger quantities. Literacy does not affect fertiliser use, while secondary education decreases the level of nitrogen applied in Aurepalle. Apparently, highly educated families make less of agriculture.

5. Conclusion and policy implications

Fertilisers are important inputs in smallholder production in India's SAT. Not only do they affect crop yields and profits, they also have a strong impact on the future production capacity of dryland soils. Currently, nutrient balances are strongly negative, and special efforts are required to maintain soil productivity. As the potential for organic fertilisation is limited, restoring nutrient balances involves a significant increase in fertiliser use. In order to design effective policy measures for achieving this goal, governments need a thorough insight into the determinants of smallholder fertiliser use.

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This study presents a model that reveals the rationale behind decisions on fertiliser use in a risky environment with financial market imperfections and well-functioning labour markets. Credit constraints can prevent farmers from buying the desired amount of fertiliser. The impact of risk is subtler. Farmers with limited options to smooth consumption will try to stabilize income. One way of doing this is adapting fertiliser use to account for the effect of fertilisers on output variability. Depending on the crop technology and the production environment, this may imply either an increase or a decrease in fertiliser intensity compared to a risk-free setting. The effects of both risk and credit constraints can be alleviated through adaptations in family labour supply: labour income provides liquidity and can stabilize total income.

The model presents a sound basis for empirical testing of the presumed relations in India's SAT. Contrary to previous studies, the empirical model allows distinction between the effects of risk and credit constraints. Estimates for two villages in India's SAT reveal that risk strongly affects fertiliser use: output variability increases the use of fertilisers in both villages. This implies that the village households utilize fertilisers to decrease risk, which coincides with the behaviour of US farmers. The effects of the farmers' asset endowment on fertiliser use confirm this observation: wealthier households, which are better able to smooth consumption, use less inorganic nitrogen in either village. On the other hand, constraints on short-term credit do not limit fertiliser use.

A starting point of this research was the notion that employment policies might affect fertiliser use. The model suggests that off-farm employment decreases the effect of risk on fertiliser use and thus leads to a lower use of fertilisers. This implies that the introduction of public works or self-employment programmes in areas with high levels of dry-season unemployment would diminish fertiliser use. Our regressions confirm this effect: fertiliser use decreases in reaction to improved off-farm employment opportunities as measured by the family labour endowment. In other words, employment programmes, although valuable in their own respect, cannot be used to promote smallholder fertiliser use.[6]

The empirical estimates suggest another interesting, although not very surprising, direction for policy. In the study period, lack of knowledge has limited fertiliser use. Older households from traditional farming families use more fertilisers than their fellow villagers do. The greater familiarity of farmers with modern inputs in later years explains probably at least part of the positive time trend for nitrogen use. Given that India's fertiliser use was still low by the end of the 1990s, it seems, nevertheless, justified to conclude that extension is even now a suitable method to stimulate fertiliser application. This is a more effective method than (changes in) price subsidies: the nitrogen price did not significantly affect the nitrogen use during the survey period.

[6] On the other hand, stimulating off-farm employment could help decrease nutrient pollution in high-production areas. To test this assertion, more information on the specific production environment in these areas is needed.

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Appendix: Derivation of the planting-stage first-order conditions

The Lagrangian for the planting-stage is:

$$\begin{aligned}\Im = {} & U[w_1(F_1 - L_1) + B, T_1 - F_1] + \rho E U[(\rho - \alpha w_2)(f(A, L_1, I) \\ & + h(A, L_1, I)\gamma\varepsilon) + w_2 F_2 - (1 + r)B, T_2 - F_2; Z] + \lambda(B_m - B)\end{aligned} \tag{A1}$$

where F_2 is a function of planting-stage decisions regarding L_1, I, and B. Besides, the first-order condition for the harvest stage is

$$U_{\ell_2} = w_2 U_{C_2} \tag{A2}$$

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The first-order condition for planting labour demand can be derived as follows

$$-w_1 U_{C_1} + \rho E\{U_{C_2}[(p - \alpha w_2)(f_{L_1} + h_{L_1}\gamma\varepsilon) + w_2 F_{2,L_1}] - U_{\ell_2} F_{2,L_1}\} = 0 \quad \text{(A3a)}$$

As $U_{\ell_2} = w_2 U_{C_2}$ (Eq A2), this reduces to

$$-w_1 U_{C_1} + \rho E\{U_{C_2}(p - \alpha w_2)(f_{L_1} + h_{L_1}\gamma\varepsilon)\} = 0 \quad \text{(A3b)}$$

Which can be rewritten as follows

$$-w_1 U_{C_1} + \rho(p - \alpha w_2)(f_{L_1} E U_{C_2} + \rho(p - \alpha w_2) h_{L_1}\gamma E(U_{C_2}\varepsilon) = 0 \quad \text{(A3c)}$$

Hence

$$f_{L_1} = \frac{w_1}{p - \alpha w_2}\frac{U_{C_1}}{\rho E U_{C_2}} - w_1\gamma\frac{E(U_{C_2}\varepsilon)}{E U_{C_2}} \quad \text{(A3d)}$$

A similar condition holds for fertiliser use.

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