Adoption of Carbon-sequestering Practices in Developing Countries and Risk-averse Farmers

ALESSANDRO DE PINTO and RICHARD ROBERTSON

Environment and Production Technology Division,

International Food Policy Research Institute, USA

a.depinto@cgiar.org

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Introduction

Agriculture plays a dual role in the climate change debate: first, it is a major source of greenhouse gas emissions; second, agriculture provides major mitigation opportunities, for example via soil carbon sequestration. Agriculture's contribution to global GHG emissions is estimated to be 10 to 14 percent of total emissions (Smith et al. 2007; Baumert, Herzog, and Pershing 2005; FAO 2009b). Agriculture is the largest source of no-CO_2 GHG emissions, generating 52% and 84% of total methane and nitrous oxide emissions, respectively. Emissions from agriculture are increasing rapidly and are expected to continue to increase in the next decades. There are also prospects for mitigation. Smith et al. (2008) assess the economic potential of agricultural mitigation of GHG emissions including livestock-based and cropland options. The global technical GHG mitigation potential for agriculture by 2030 was estimated to be about 5500-6600 Mt CO_2-eq.year^{-1}. Most of the GHG mitigation potential in agriculture comes from soil carbon sequestration. Soil carbon sequestration represents an important mitigation option, potentially more viable than N_2O reductions (USEPA 2006).

A small but growing body of literature investigates the conditions favoring adoption of climate change mitigation practices by farmers in developing countries. The analysis is generally kept straightforward: virtually all authors, (Stavins 1999, Antle 2002; Gonzales-Estrada et al. 2008 among many) assume that a risk-neutral farmer will try to maximize the present value of the stream of net benefits that derive from farming land. A farmer will therefore adopt mitigation practices when the net present value of farming with these practices is greater than with the alternatives. Uncertainty and risk-aversion is notably absent in the modeling of farmers' adoption of climate change mitigation practices in developing countries. However, as Antle and Stoorvogel (2008) point out: "it is important to note that risk could impact farmers' willingness to participate in carbon contracts both positively and negatively." Furthermore, it should be noted that of the twenty mitigation practices identified in a recent FAO report (FAO 2009a), seventeen explicitly have an effect on yield variability, of which, fourteen reduce variability (Table 1). There is plenty of evidence that farmers are not likely to be neutral to risk and actually tend to be risk averse (Antle 1987; Chavas and Holt 1990; Bar-Shira, Just, and Zilberman 1997; Hennessy 1998; Just and Pope 2002; Serra et al. 2006; Yesuf and Bluffstone 2007) and that risk considerations affect input usage and technology adoption (Just and Zilberman 1983; Feder, Just, and Zilberman 1985; Kebede 1992). We therefore believe that risk considerations cannot be ignored in the analysis of the impact of payments for carbon sequestration.

The main objective of this paper is to explore some of the implications for climate change mitigation projects of modeling farmers as risk-neutral while in actuality they behave as risk-averse agents. As it will be analyzed later in the paper, the inclusion of risk considerations provides important insights on the reasons programs can succeed or fail and in the complexities of program implementation.

Effects of the Risk-neutrality Assumption

To further appreciate the theoretical aspect of the problem and the potential importance of accounting for risk-aversion, we exploit Feder's analysis of risk-averse farmers and input choices (Feder, 1980). We show that it is possible to overestimate the cost of inducing adoption of a yield-variability-reducing input when in presence of risk aversion. Consider a Just and Pope (Just and Pope, 1978) formulation of the production function:

$$q = y(x) + \varepsilon h(x)$$

Where q indicates output, y is the average output, x is an input, ε is a random variable with mean zero, and $h(x)$ is a term that determines output variability. Also assume that:

$$y' = \frac{dy}{dx} > 0;\ h' = \frac{dh}{dx} < 0$$

A researcher observes a farmer who uses input x in the amount of x^* assuming that the choice is the result of an expected profit maximization process for a risk-neutral farmer.

The risk-neutral farmer will use input x in amount equal to x^* such that:

$$py'(x^*) = c'(x^*)$$

Assume one could require the farmer to use more of input x, buying x at its market price w. The change in expected profit is given by:

$$\mathrm{dE}[\Pi] = py'(x^*)dx - c'(x^*)dx$$

One could compensate the farmer by giving her a lump-sum such that the expected profit remains unchanged:

$$\mathrm{dE}[\Pi] = py'(x^*)dx - c'(x^*)dx + dS = 0$$

Which is to say, the lump sum dS is "tailored" to a risk-neutral farmer such that if the farmer uses more of input x she will not be worse off than in her original situation. Suppose the farmer is in actuality risk-averse and had chosen x^* to maximizes expected utility

$$\mathrm{E}[\mathrm{U}(\Pi)] = \mathrm{E}\{\mathrm{U}[py(\mathrm{x}^*) + p\varepsilon h(\mathrm{x}^*) - c(\mathrm{x}^*)]\}$$

where the utility function has the following characteristics:

$$\mathrm{U}' > 0;\ \mathrm{U}'' < 0$$

Consider the effect on expected utility of the change imposed on the farmer inclusive of the lump sum payment:

$$\mathrm{dE}[\mathrm{U}(\Pi)] = \mathrm{E}\{\mathrm{U}' * [py'(\mathrm{x}^*)dx + p\varepsilon h'(\mathrm{x}^*)dx - c'(\mathrm{x}^*)dx + dS]\},$$

is the change in expected utility $\mathrm{dE}[\mathrm{U}(\Pi)]$ also equal to zero?

Note that: $py'(x^*)dx - c'(x^*)dx + dS = 0$ and therefore:

$$\mathrm{dE}[\mathrm{U}(\Pi)] = \mathrm{E}[\mathrm{U}' * (p\varepsilon h'(\mathrm{x}^*)dx)].$$

Given the non-stochastic nature of p, h', dx:

$$\mathrm{dE}[\mathrm{U}(\Pi)] = ph'(\mathrm{x}^*)dx\ \mathrm{E}[\mathrm{U}' * (\varepsilon)].$$

Since $h' < 0; p > 0; dx > 0$, the sign of $\mathrm{dE}[\mathrm{U}(\Pi)]$ depends of the sign of $\mathrm{E}[\mathrm{U}' * (\varepsilon)]$ and since $\mathrm{E}[\mathrm{U}' * (\varepsilon)]$ is always <0 (for a detailed demonstration see the appendix A in Feder 1980), it follows that $\mathrm{dE}[\mathrm{U}(\Pi)] > 0$.

Therefore, a payment that compensates a farmer for the use a of a yield-variability-reducing input beyond optimality, and the payment is such that leaves expected profit unchanged, increases the expected utility of a risk-averse farmer. Similarly, if the use of an input increases yield variability, the payment for a risk-neutral farmer underestimates the payment necessary for a risk-averse farmer that keeps utility constant.

An Empirical Application

As mentioned in the introduction, what motivates this paper are the numerous studies that have investigated the conditions for adoption of climate change mitigation practices assuming that farmers ignore risk in valuing their production decisions. The approach is best exemplified by Antle (2002) where the net present value of switching form a land use or agronomic practice *j* to a carbon-sequestering practice *i* is expressed as follows:

$$NPV(i,j) = \sum_{t=1}^{t=T} \frac{1}{(1+r)^t} [NR_i(p_t, w_t) + P_t \Delta C_t - M_t(i,j)] - I(i,j)$$

Where, *r* is the annual interest rate, *NR* is the net returns for agronomic practice *i* in period t, given product price *p*, input prices *w* , $P_t \Delta C_t$ is the per-tonne payment, $M_t(i,j)$ is the maintenance cost per period for changing from system *j* to *i,* and $I(i,j)$ are fixed cost for changing from system *j* to system *i*. Given this framework the farmers switches to the carbon-sequestering land use or practice if

$$NPV(i,j) \geq NPV(j)$$

For our empirical application we will be looking at profit rather than net present value although this simplification that does not detract from the general point made in this paper.

We follow Just and Pope and assume that farmers' per hectare production function can be represented by the following:

$$q = f(x, \boldsymbol{z}) + \varepsilon h(x)$$

Where, q indicates output, x is a variable input and $\boldsymbol{z}$ vector of fixed inputs, ε is a random variable with mean zero, and $h(x)$ determines output variability[1].

[1] We acknowledge here that we are making the simplifying assumption input interactions do not influence output variance.

We also assume that farmers' profit is defined as follows:

$$\Pi = pq(x, \boldsymbol{z}) + p\varepsilon h(x) - C(x, \boldsymbol{z}) + S$$

where p is the output price, and S is a payment for a positive externality generated by farmers (carbon sequestration in our case). This implies that the mean and standard deviation of profit are:

$\mu_{\Pi} = pq(x, \boldsymbol{z}) - C(x, \boldsymbol{z}) + S$ and $\sigma_{\Pi} = ph(x)$

We choose to model our representative farmer as a risk-averse agent and we assume that her utility can be characterized by a mean-standard deviation utility function. Explored originally by Tobin (1958) and Markowitz (1959) and then rediscovered and clarified by Meyer (1987), the mean-standard deviation approach is appealing for its simplicity and tractability. Meyer demonstrated that under certain conditions, the location-scale condition and convexity in the mean- standard deviation space, the expected utility and mean standard deviation are analytically equivalent. However, part of the economic literature (Saha 1997, Ormiston and Shlee 2001, Isik and Khanna 2003, Eichner 2008) takes the mean-standard deviation approach as a framework that stands on its own. The advantage of this approach is the flexibility in representing risk attitudes and their empirical tractability. As we will discuss later in the paper, we believe that for a correct planning of policies promoting adoption of mitigation practices farmers' risk attitudes cannot be ignored. We therefore opted to use the mean-standard deviation approach which lends itself more easily to be in empirical studies.

Consequently, we follow Saha (1997) and we assume that farmers' preferences can be represented by a mean-standard deviation utility function $\mathrm{V}(\mu, \sigma) = \mu^{\theta} - \sigma^{\gamma}$ where θ is assumed to be greater than 0. Under this specification, farmers' attitude towards risk is captured by the slope of the indifference curve in the μ, σ space $\quad \mathrm{R} = -\frac{V_{\sigma}}{V_{\mu}} = \frac{\gamma}{\theta}\mu^{1-\theta}\sigma^{\gamma-1}$. Risk aversion (neutrality) [affinity] corresponds to $\gamma > (=)[<]0$. Under the assumption of risk aversion, decreasing (constant) [increasing] absolute risk aversion preferences require $\theta > (=)[<]1$. Furthermore, decreasing (constant) [increasing] relative risk aversion is denoted by $\theta > (=)[<]\gamma$.

The simulation settings

The objective of the program sketched in our simulations is to induce farmers to adopt climate change mitigation practices. In order to simplify the simulation settings, we concern ourselves only with carbon sequestration and assume that sequestration is dependent directly (and only) on usage of input *x*. We also assume that producers are operating with an optimal choice of inputs without the program, hence any change in the amount of input *x* used will make them less well off. We want to compute the lump-sum payment *S* necessary to make producers indifferent between using or not using prescribed levels of *x*.

Under profit maximization the farmers adopts the carbon sequestering input if

$$\Pi_A + S \geq \Pi_N$$

While under utility maximization the conditions for adoptions are the following:

$$\mathrm{U}(\Pi_A + \mathrm{S}, \sigma_\mathrm{A}) \geq \mathrm{U}(\Pi_N, \sigma_\mathrm{A})$$

Our initial conditions are that the relative price of the input under consideration is high enough to make its use unprofitable and that therefore farmers are not using the input[2]. We wish to simulate a payment program which will move farmers from no usage to some target amount $\mathrm{x_T}$. The use of this input will have a direct effect on yields, but also on yield-variability and the amount of carbon sequestered in the soil.

We used the DSSAT crop modeling system (Hoogenboom and Jones 2004; Jones, Thornton, and Heinke 2009) to simulate maize yields and soil carbon content. Crop simulation models are a process based approach to numerically growing a crop. Starting with weather data, soil data, and management practices, the model grows the plant by considering the water, sunshine, and available nutrients in order to grow the virtual roots, stems, leaves, and fruits. The models are approximations based on a physiologic understanding of the particular plant with the details being calibrated against field trials. A necessary part of this process is a soil model (CENTURY)

[2] The motivation for this choice, besides that it simplifies the modeling settings, are the many observed cases where ecologically friendly practices are not utilized even though basic economic analysis predicts that such practices would be more profitable than the alternative choices. We are trying to capture this common situation in a pure neoclassical setting without resorting to problems related to institutions, market imperfections, knowledge gaps, and the like.

which keeps track of water and nutrients extracted from the soil (and the fertilizers and irrigation water added) as well as the decomposition of organic matter. This constellation of features makes crop models powerful tools for analyzing management practices. In our case, we are interested in yield levels and variability as well as changes in soil organic carbon content resulting from applying different amounts of organic matter.

We simulated a very simple cropping system that alternates maize during the growing season with fallow ground during the off-season for twenty years. The daily weather data were simulated using DSSAT's internal stochastic weather generator. For each year we record the yield as well as the soil carbon content. In order to obtain an estimate of yield variability, we repeated the entire process 100 times using a different random seed each time. The input we investigated was an organic soil amendment, such as green manure (no other fertilizers were used), and we simulated 13 levels of use intensity, ranging from zero to 20 tons per hectare. Through this series of simulations we obtain yields, yield-variability, as well as the soil carbon content at the end of the period.

Simulated yields were used to compute profit. The output price was set to \$0.42/kg **(**this price was taken from González-Estrada et al. 2008). The input price was chosen as the lowest possible price that ensures that the producer would choose not to use the input, under both risk-neutrality and risk-aversion. For this particular combination of choices, an input price of \$0.0739 worked well. The profit function is derived directly from the input costs and yield simulations from DSSAT while the mean-standard deviation utility function is $V(\mu, \sigma) = \mu^{0.4} - \sigma^{0.6}$.

Figure 1 provides a representation of the production function for two different years, years two and twenty. The simulation seems to indicate that increasing green-manure application from seven to nine tons per hectare has a remarkable effect on yields. This rapid increase in output is observed for all years even though the input-output ratio changes through time as can be seen both in

Figure 1 and Figure 2. Figure 2 shows how the yields change through time for several different levels of input usage. The differences in yields both through time and with respect to the amendment amount are due to the continuously evolving soil characteristics as new manure is incorporated into the soil and the plant draw nutrients from it.

We are particularly interested on the effect of input usage on yield variability. This is shown in Figure 3. Since soil characteristics evolve through time due to both the uptake of soil nutrients during production and green-manure applications, the effect is different for different years. It is important to note how different input applications can increase or decrease yield variability compared to no usage. For example, for year 2 from about 9000 kg of manure, yield variability is lower than with no input usage. However, note how in year 20, the standard deviation is higher than no usage for virtually all levels of applications.

Once yields and standard deviation are simulated, it is possible to determine the payment necessary to induce participation at each input level. This is achieved by setting the utility under participation (with the higher input usage) equal to the utility without participation and solving for the payment. Figure 4 shows the sum of all the minimum yearly payments necessary to induce adoption under profit and utility maximization. Given our assumptions about the utility function, if the quantity of input use results in higher yield variability the payment necessary to induce adoption will be higher under risk aversion than under risk neutrality. The opposite is true when the use of the input reduces the yiled standard deviation. This is reflected in Figure 4. For example, applications in the range of five tons of green manure (in general) increase yield standard deviation and this acts as a penalty for a risk farmer. The resulting minimum payment to induce adoption is higher under risk-aversion than risk-neutrality. Conversely, applying some ten tons of the input decreases yield standard deviation and this results in payments for risk-averse farmers that are lower than risk-neutral farmers. The result is that there are levels of input usage - below some 8,400 Kg/hectare and above some 17,800 Kg/hectare - for which the total payments necessary to induce adoption are higher under a risk-aversion assumption compared to risk-neutrality. In between these input quantities, the total necessary payments are lower for a risk-averse farmer.

The DSSAT crop modeling system can be used to simulate the amount of soil organic carbon stored in the soil. Considering the soil organic carbon accumulated under the no use scenario our baseline, we can compute the additional amount of carbon stored in soils under the adoption scenario. Figure 5 shows graphically the difference between the soil carbon at the end of each year as compared with using no green manure. Thus, the blue line representing no input usage is coincident with the x-axis. Once the payments necessary to induce adoption and the additional carbon stored in soil are computed, we can calculate the implicit cost of sequestering atmospheric carbon from the program manager's point of view as shown in Figure 6. The lowest cost per ton of sequester carbon is about $67.5 under risk-neutrality assumption while for a risk-averse farmer the lowest cost is about $49.0.

Discussion of the Results and Conclusions

It is well known that programs aiming to induce adoption of carbon-sequestering practices by offering a per-hectare payment are not cost effective because will attract farmers that have a marginal cost of abatement lower or equal to the payment. The inefficiencies are so high that, as Antle et al. (2003) demonstrate, even programs that offer a payment per ton of carbon sequestered can be more cost efficient once a carefully executed sampling survey is put in place. Their work clearly exposes the extra costs a project can incur when important economic principles are ignored. Our findings also suggest that simple per-hectare payment schemes may incur in many problems.

As expected, our results indicate that when risk-averse farmers are modeled as risk-neutral agents, the size of the incentives needed to induce participation to a carbon sequestration program is miscalculated. Payments computed using a risk-neutral framework are either higher than necessary when farmers experience a reduction in risk or, when farmers confront an increase in production risk, lower than required to induce the adoption of desirable practices. These results are entirely due to the inclusion of risk considerations in the farmer's decision process. It is important to note that the differences in payments and implicit cost of carbon reported in this study depend completely upon the details of the assumptions and on the parameters that characterize the utility function. For example, it can be seen in Figure 7 that the implicit cost of carbon changes as the value of the parameter gamma is varied.

The lowest price of a ton of carbon for these values of gamma range from $67.5 to $48.9. Conceptually, when the input reduces yield variability, risk-averse preferences could drive the carbon price arbitrarily close to zero (or even negative meaning that farmer would actually prefer to use the input rather than not). In the other direction, if the input actually increases variability, then the payment necessary to induce participation can grow unboundedly depending on how much the producers wish to avoid uncertainty.

All this suggests that more empirical work on estimating risk attitudes of farmers in developing countries is needed. We believe that this work is important for the implementation of climate change mitigation programs and payment for environmental services in general. The heterogeneity of the pool of potential participants with their risk attitudes will have a strong impact on the payment needed to induce adoption and complicate considerably the implementation of these types of programs. Our simulations suggest that programs that promote the adoption of risk-reducing practices can incur in lower costs and that maybe the focus should be put on those agronomic techniques that decrease production risk. In this regard, education and information distribution (*e.g.,* extension systems) lie somewhere between important and essential. It is still possible that risk -increasing agronomic practices could, in principle provide low carbon prices if they provide a sufficiently high capacity of sequestering carbon.

Figure 1. Yields for different levels of input usage in year two and twenty.

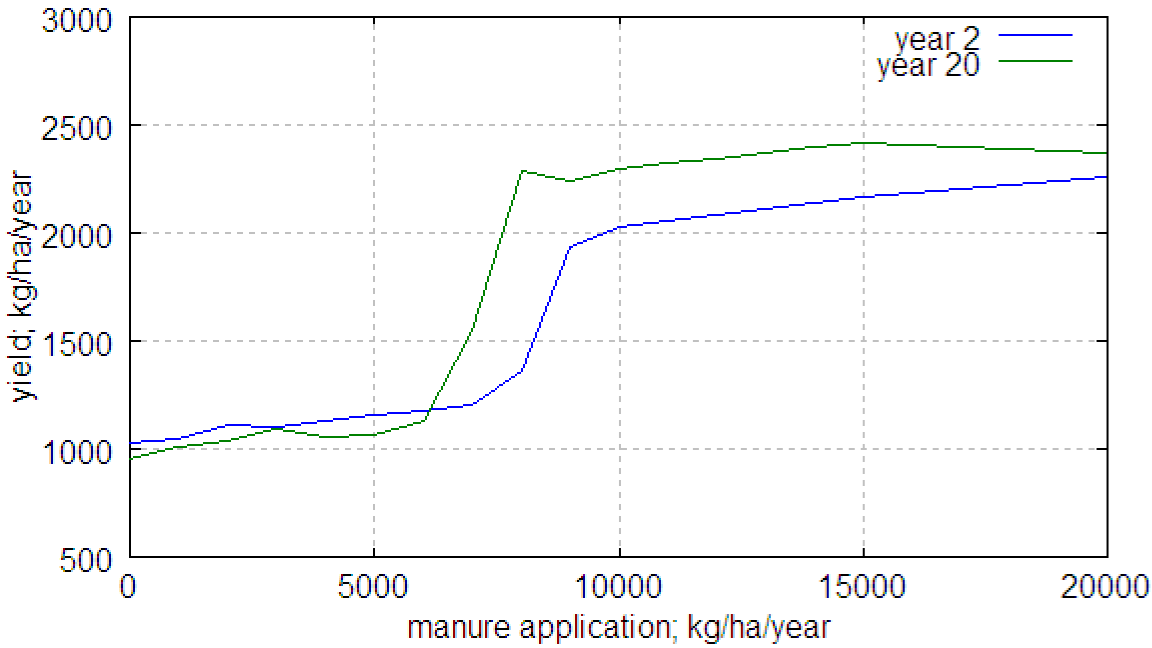


Figure 2. Effect of various input usage on yields at different points in time

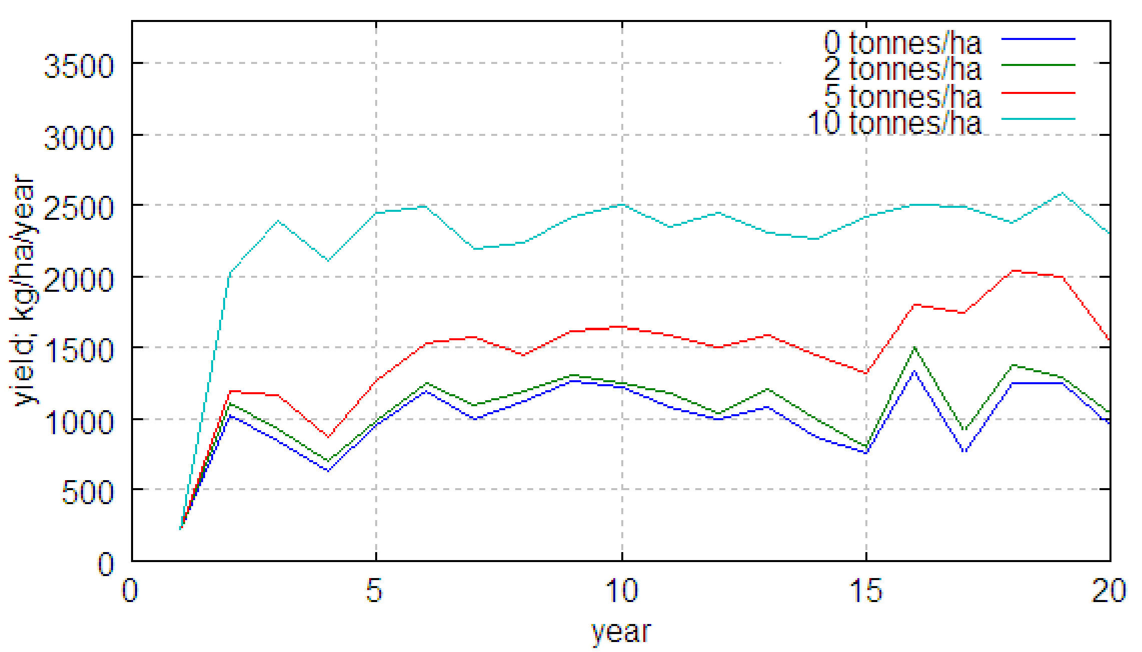


Figure 3. Effect of the input usage on yield variability for years two and twenty.

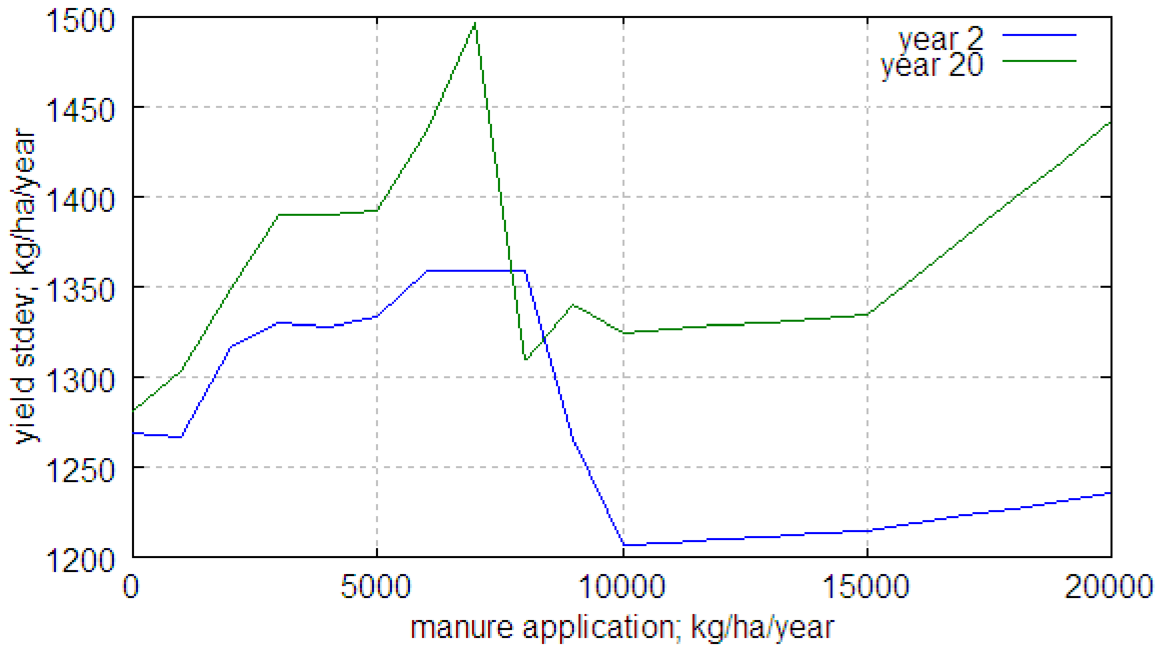
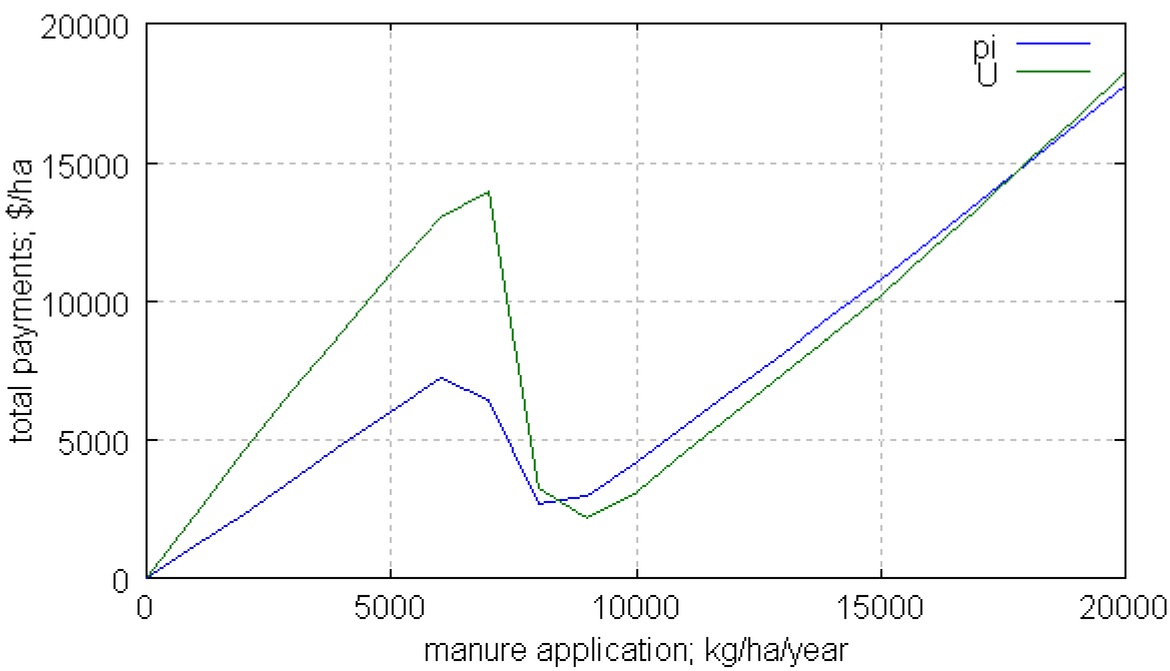


Figure 4. Total payments necessary to induce adoption under risk-aversion and risk-neutrality for different levels of input usage*



*Note: For simplicity we assume an interest rate equal to 0.

Figure 5. Soil organic carbon accumulation expressed in CO_2 for different application rates

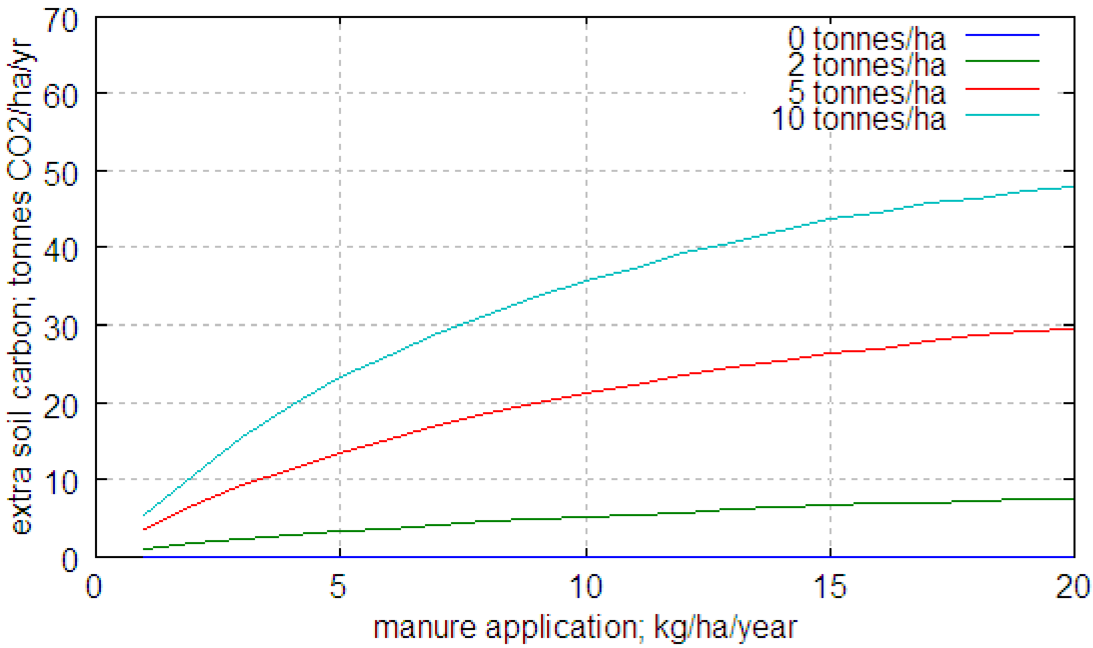


Figure 6. Implicit cost of sequestered carbon under profit and utility maximization

Figure 7. Cost of a ton of carbon sequestered under different risk profile

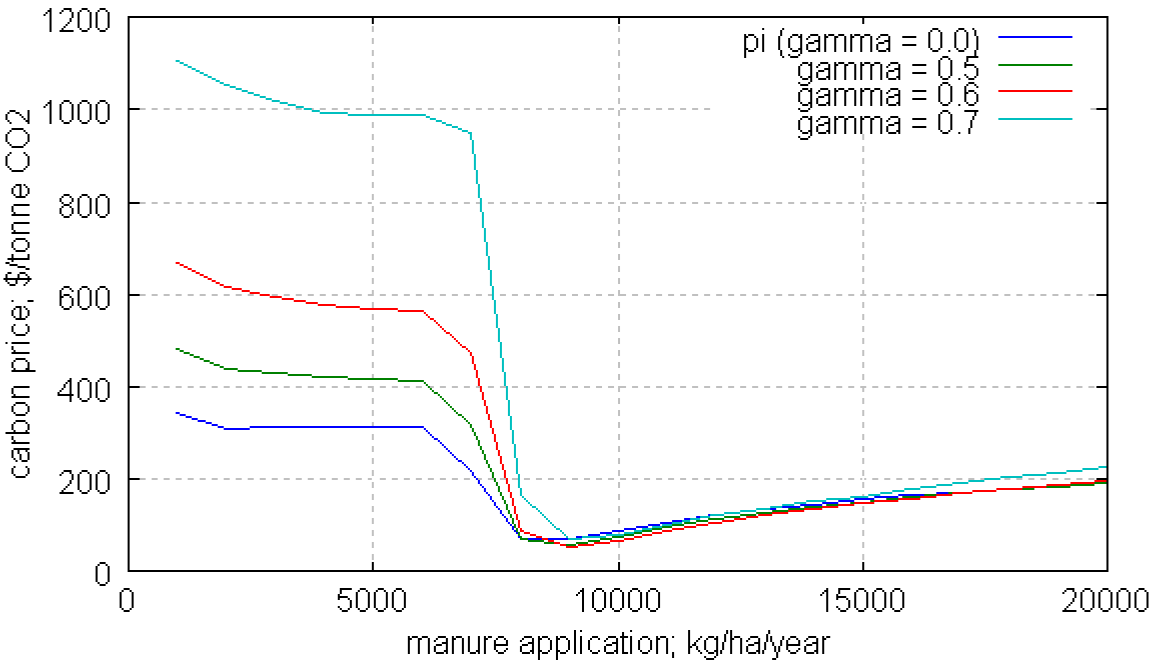


Table 1: Agricultural mitigation practices and impact on yield variability

Improved agronomic practices	
Use of cover crops	Reduced variability due to increased soil fertility, water holding capacity
Improved crop/fallow rotations	Reduced variability due to increased soil fertility, water holding capacity
Improved crop varieties	Reduced variability where varieties are developed for resilience; greater diversity of seed varieties should reduce variability at the local/sub-national level
Use of legumes in crop rotation	
Integrated nutrient management	
Increased efficiency of N fertilizer; organic fertilization; legumes and green manure; compost; animal manure	Lower variability more likely where good drainage and drought infrequent; experience can reduce farm-level variability over time Potentially greater variability with frequent droughts
Tillage/residue management	
Incorporation of residues	Reduced variability due to increased soil fertility, water holding capacity
Reduced/zero tillage	Reduced variability due to reduced erosion and improved soil structure, increased soil fertility, better pest control and improved water retention
Water management	
Irrigation	Reduced variability in well-functioning systems
Bunds/zai	Reduced variability in dry areas with low likelihood of floods and/or good soil drainage
Terraces, contour farming	Reduced variability due to improved soil quality and rainwater management
Water harvesting (e.g. runoff collection techniques, water storage tank construction, devices for lifting and conveying water)	
Perennials and Agroforestry	
Live barriers/fences	Reduced variability
Various agroforestry practices: undersowing of Tephrosia vogelii, pigeon pea and Sesbania sesban in maize for soil fertility improvement; dispersed tree interplanting (e.g. Faidherbia, Acacia polycantha, A.galpiniii. + contour grass hedges)	Reduced variability of agroforestry products; also likely reduced variability of crops due to improved soil fertility and structure, and greater water holding capacity
Improved pasture management	
Improving forage quality and quantity	Reduced variability where improved forage is adapted to local conditions Potentially increased variability where improved forage is more sensitive to climate conditions than natural pasture
Seeding fodder grasses	Reduced variability where seeded fodder is adapted to local conditions Potentially increased variability where improved seeded fodder is more sensitive to climate conditions than natural pasture
Improving vegetation community structure (e.g. seeding fodder grasses or legumes; reducing fuel load by vegetation management)	Reduced variability due to improved soil structure, reduced erosion

Improved grazing management	
Stocking rate management	Potentially lower variability in long-term, where forage availability is key factor in livestock output variability
Rotational grazing	Potentially lower variability in long-term, where forage availability is key factor in livestock output variability
Restoring degraded land	
Re-vegetation	Reduced variability in local landscape due to reduced wind, soil, and/or water erosion
Applying nutrient amendments (manures, biosolids, compost)	

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