The Quasi-Option Value of Delayed Input Use under Catastrophic Drought Risk: The Case of No-Till in Morocco

Nicholas Magnan, Travis J. Lybbert, Rachid Mrabet, and Aziz Fadlaoui

Worldwide, over two-thirds of all cereal-producing land is in rainfed areas: 40% of rice, 66% of wheat, 82% of maize, and 86% of other coarse grains (Rosegrant et al. 2002). Many farmers cultivating this land face high and increasing drought risk due to climate change. The frequency of drought in Morocco, for example, has increased from one in eight years in 1940–1979 to one in three years in 1980–1995 to one in two years in 1996—2002 (Balaghi et al. 2007; Barakat and Handoufe 1998). Similar trends throughout the Mediterranean region and worldwide have pushed drought risk management to the forefront of policy discussions and agricultural research (Mrabet 2008).

Farmers and researchers alike work hard to create, adapt, and adopt varieties and technologies that reduce the impact of drought on yields, but in years of catastrophic drought the crop is often not worth harvesting, regardless of the variety or technology used. In this paper we develop a simulation model calibrated with data from Morocco to demonstrate how no-till agriculture, a technology that delays input use, creates a quasi-option value for farmers faced with the possibility of catastrophic drought. Quasi-option value is the value gained by waiting for additional information before making an irreversible investment (Arrow and Fisher 1974). While quasi-option value may be small compared with the total benefits of adoption, it should be readily understood by farmers and therefore could play a key role in the adoption decision.

Background: No-Till and Drought Risk

No-till agriculture (NT) allows farmers to forgo plowing by seeding directly through the stubble of previous years' crops, which the farmer is required to leave on the field. Because the farmer does not plow, NT lowers planting costs. NT also benefits the farmer by improving soil quality, resulting in more efficient water use and higher yields in years of mild drought. Furthermore, NT provides many environmental benefits not fully internalized by the farmer, such as lowered emissions, reduced erosion, and increased soil organic carbon, which causes the soil to act as a carbon sink (Mrabet 2008). In addition to lowering overall production costs, NT changes input timing so that relatively fewer costs are incurred early in the growing season compared with costs incurred with conventional tilling (CT) (e.g., lower preplanting costs) and relatively more costs are incurred later in the growing season (e.g., higher weed management costs). If farmers can abandon their crop in response to catastrophic drought before making late-season investments, a quasi-option value is generated.

The feasibility of NT for rainfed agriculture in Morocco has been assessed since the 1980s. Despite promising results, uptake by farmers is sparse and conventional methods continue to dominate (Mrabet 2008). To encourage adoption, NT proponents must effectively convey the benefits (and drawbacks) of NT to potential adopters. Of the many benefits, quasi-option value of delayed input use has not yet been extensively explored or discussed. This is an

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unfortunate void because quasi-option value may compose a substantial portion of the cost savings from using NT, and may be more immediately apparent to farmers than more complex, and often longer-run, production and environmental benefits. A cursory explanation of NT is sufficient to convey quasi-option value to rainfed farmers with sufficient experience with catastrophic drought.

Drought risk and drought risk management occur on three distinct levels. First, there is rainfall risk, specifically variance in the amount and timing of rainfall. The farmer can do nothing to manage drought risk on this level, besides relocating to a different microclimate more amenable to rainfed agriculture (Fafchamps 2003) or installing irrigation to control water availability (Van Noordwijk, Dijksterhuis, and Van Keulen 1994). Second, there is yield risk, or variation in yields due to year-to-year differences in rainfall. To adapt to yield risk, farmers can choose crops, varieties, and techniques that are better suited to deal with this variation. In the present context, NT appears to reduce yield risk (Ding, Schoengold, and Tadesse 2009; Mrabet 2008). Third, there is income risk, which is ultimately what matters to agricultural households. Management strategies for income risk are numerous and well documented; Fafchamps (2003) and others provide reviews. One of the many ways income risk can be managed is through flexibility, that is, having the ability to change production decisions as more information about nature is gathered (Fafchamps 2003; Giné, Townsend, and Vickery 2009; Van Noordwijk, Dijksterhuis, and Van Keulen 1994).

One example of flexibility is adjusting input use during the growing season. Fafchamps (1993) finds that rainfed farmers choose the amount of crop to plant in order to maximize flexibility of weeding labor in response to rainfall. Another example of flexibility is replanting. When early rains abruptly stop, the crop fails and the farmer must replant. Under such circumstances a farmer may choose what crop or variety to cultivate based on flexibility of planting date or length of growing cycle in order to facilitate replanting, sacrificing expected yield for flexibility (Chavas, Kristjanson, and Matlon 1991; Fafchamps 2003). Farmers may also make less early season investment if the expected arrival date of early season rains is highly uncertain (Giné, Townsend, and Vickery 2009).

In dryland ecosystems, it is not uncommon for farmers to abandon their crop in response to catastrophic drought. A technology that allows farmers to push input costs beyond some critical abandonment point in the season offers greater flexibility because a farmer who abandons a crop will have more resources to use toward planting a second crop or for another activity (i.e., investment in livestock, off-farm investment, or consumption). Although underappreciated as yet, NT potentially increases flexibility in this way.

Before moving to our model, we consider the extent and timing of crop abandonment by rainfed wheat farmers in Morocco. We surveyed 197 rainfed wheat farmers in the cereal-growing Meknès region following the drought-plagued 2006–2007 agricultural year, and resurveyed 190 of the same farmers following the 2007–2008 agricultural year, which was characterized by normal rainfall. All farmers in the region used mechanized CT or traditional tillage (animal-drawn plows) at the time of the surveys (NT has not yet been widely disseminated). Of the 197 wheat farmers surveyed in 2007, 91 abandoned at least one plot; in all, 152 of the 337 rainfed wheat plots were abandoned. Of the 190 farmers resurveyed in 2008, only 3 abandoned a plot.

Actual CT input use calendars vary by farmer but are generally as follows. The farmer first plows his fields in the summer before the November to June growing season, and plows again closer to planting time. Following the first rains in early November, the farmer seeds and applies starter fertilizer. He then applies herbicide near the end of December, additional fertilizer in late February, and fungicide and additional herbicide (or manual weeding) in March or April, as necessary. The farmer harvests in late May or early June. Each point on the input calendar represents a decision point; when the crop calls for an input, the farmer can either make that investment and continue with the season, or not make the investment and abandon the crop. If farmers exactly follow this recommended calendar, those abandoning in March would stand to save on fertilizer, fungicide, weeding or herbicide, and harvesting costs. Those farmers abandoning thereafter would save on harvest and possibly weeding costs (although weed pressure would typically be low in a drought year). March is also a logical point to decide on abandonment given that in most years 70% of growing season rain falls between November and March (Mrabet 2008).

Indeed, many surveyed farmers who abandoned a plot did so in March. Abandonment

Table 1. Differences in Input Use Between Harvesting and Abandoning Farmers

		N	Fert 1	Fert 2	Weed	Herb	Fung	Insect
Soft	Harvesting	124	99.2	82.2	18.5	40.3	15.3	7.3
	Abandoning	88	100	65.9	12.5	23.9	9.1	3.4
	P-value (χ^2)		0.40	0.01	0.24	0.01	0.18	0.23
Durum	Harvesting	43	100	83.7	23.3	34.9	27.9	4.7
	Abandoning	28	100	67.9	14.3	32.1	10.7	3.6
	P-value (χ^2)		1.0	0.118	0.353	0.811	0.083	0.825

Note: Fert 1 denotes starter fertilizer, Fert 2 denotes cover fertilizer, and Weed denotes manual weeding. Herb, Fung, and Insect denote the corresponding pesticides.

continued, albeit at a lower rate, throughout April, and then increased at harvest time.[1] Farmers were equally likely to use starter fertilizer on plots that were ultimately abandoned as on those that were not, but less likely (although not always significantly so) to use late-season inputs, suggesting that there are no fundamental *ex ante* differences in input use (table 1). A sophisticated empirical study of abandonment timing and input use is beyond the scope of this paper and not possible with the available data. However, these observations suggest that farmers save on inputs by abandoning midseason, and therefore technologies that delay input use past some critical decision point offer a quasi-option value.

Model

We begin by adapting existing models of farmer flexibility to include technology choice (Chavas, Kristjanson, and Matlon 1991; Fafchamps 2003). A farmer aims to maximize expected profit by growing wheat using technology $j = \{\mathrm{CT}, \mathrm{NT}\}$, where revenue y^j is a function of input spending $\boldsymbol{a^j}$ and a stochastic rainfall event q, where $i = \{$catastrophic drought, mild drought, good rainfall$\}$. We assume that output prices are the same for wheat produced using both technologies and under all possible rainfall events, so revenue is simply yield times a price constant. We subdivide $\boldsymbol{a^j}$ into early season, a_1^j, and late season, a_2^j, spending. The probability of rainfall event q_i is $P(q_i)$ and $\sum_i P(q_i) = 1$. The sequence of actions and events is a_1^j, q, a_2^j. Quasi-option value is not dependent on risk aversion (Arrow and Fisher 1974), although the model can easily be extended to a risk-averse farmer.

An inflexible farmer solves the entire optimization problem before the realization of q_i. This is termed an open-loop problem, and is defined as

$$(1) \qquad E[\Pi_{Inflex}(j, a_1^j, a_2^j, q)] = \underset{j, a_1^j, a_2^j}{\mathrm{Max}} \sum_i y^j(a_1^j, a_2^j, q_i) \cdot P(q_i) - a_1^j - a_2^j.$$

The inflexible farmer will pick technology j and input plan a^j to maximize expected profit. A more realistic scenario is the flexible farmer's problem, where the farmer decides j and a_1^j before q is known and a_2^j after. This is termed a closed-loop problem, and is defined as

$$(2) \qquad E[\Pi_{Flex}(j, a_1^j, a_2^j, q)] = \underset{j, a_1^j}{\mathrm{MAX}} \sum_i \left[\underset{a_2^j}{\mathrm{MAX}}\, y^j(a_1^j, a_2^j, q_i) - a_2^j \right] \cdot P(q_i) - a_1^j.$$

Expected profit under the closed-loop problem will always be as great as expected profit under the open-loop problem because closed-loop problems allow for changes in the production plan in response to added information.

Farmers exploit flexibility of input use under uncertainly in several ways. Here we focus on a simple decision of whether to abandon a crop ($a_2^j = 0$) or use some prescribed dosage $\hat{a}_2^j$. We assume that abandonment is irreversible and that if a farmer abandons his crop, he

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[1] Farmers in Morocco typically divide the growing season into ten-day "decades." Of the twenty-one decades from November 2006 to May 2007, over a quarter of all crop abandonment decisions were made in the three decades in March.

receives nothing.[2] The inflexible farmer solves equation (1) in a single step and will adopt NT if the expected net profits from adoption are positive, i.e.,

$$(3)\quad \begin{aligned}\Delta E[\Pi_{\mathit{Inflex}}] &= E[\Pi_{\mathit{Inflex}}(NT, a_1^{NT}, a_2^{NT}, q)] \\ &\quad - E[\Pi_{\mathit{Inflex}}(CT, a_1^{CT}, a_2^{CT}, q)] \\ &= \sum_i y^{NT}(\hat{a}_1^{NT}, \hat{a}_2^{NT}, q_i) \\ &\quad \cdot P(q_i) - \hat{a}_1^{NT} - \hat{a}_2^{NT} \\ &\quad - \sum_i [y^{CT}(\hat{a}_1^{CT}, \hat{a}_2^{CT}, q_i) \cdot P(q_i) \\ &\quad - \hat{a}_1^{CT} - \hat{a}_2^{CT}] > 0.\end{aligned}$$

Because the inflexible farmer cannot take advantage of the quasi-option value conferred by NT, this profit differential stems from differences in costs (assuming late season investment) and yields. The flexible farmer solves equation (2) recursively in two steps. The first step is to develop the following contingency plan for each possible draw of q under both technologies:

$$(4)\quad a_2^j(q_i) = \begin{cases} \hat{a}_2^j & \text{if } y^j(\hat{a}_1^j, \hat{a}_2^j, q_i) - \hat{a}_2^j > 0 \\ 0 & \text{otherwise} \end{cases}.$$

The second step is to decide what technology to use based on the optimal contingency plan. The farmer adopts NT if the expected net profits from adoption are positive, i.e.,

$$(5)\quad \begin{aligned}\Delta E[\Pi_{\mathit{Flex}}] &= E[\Pi_{\mathit{Flex}}(NT, a_1^j, a_2^j, q)] \\ &\quad - E[\Pi_{\mathit{Flex}}(CT, a_1^j, a_2^j, q)] \\ &= \sum_i \big[[y]^{\mathrm{NT}}(\hat{a}_1^{\mathrm{NT}}, a_2^{\mathrm{NT}}(q_i), q_i) \\ &\quad - \hat{a}_1^{\mathrm{NT}} - a_2^{\mathrm{NT}}(q_i)\big] \cdot p(q_i).\end{aligned}$$

In contrast to the inflexible farmer, this profit differential includes the quasi-option value (QOV) of delayed input use. Thus, $\Delta E[\Pi_{\mathit{Flex}}] = \Delta E[\Pi_{\mathit{Inflex}}] + QOV$. In the next section, we use this relationship in expected profit differentials to calculate the quasi-option value of NT.

Calibration and Simulation

To calibrate the model, we use NT and CT input quantities and application dates from the National Agricultural Research Institute of Morocco (INRA). Price data were collected from input dealers and service providers in the Meknès region in March 2010. Rainfall and yield data were taken from a nine-year (1994–2003) NT versus CT experiment in the Chaouia region, which has similar climate and soil characteristics as Meknès (Mrabet 2010). Using the model, we calculate the net benefits and quasi-option value of NT versus CT under different probabilities of drought.

Approximate best-practices input timing for soft wheat production under CT are as described in the "Background" section of this paper. Approximate best practices under NT are as follows. The farmer does not plow, but uses herbicide to prepare the seedbed before planting. The farmer then seeds in early November, using a special seeder but the same dosage of seeds and fertilizers as with CT.[3] Fungicides and additional fertilizers are used at the same time, and in equal quantities, under NT and CT. Under NT, chemical or manual weeding takes place in March or April if necessary, and we assume that weeding is more costly under NT than under CT, either because it requires more intensive use of chemical herbicides (Nail, Young, and Schillinger 2007) or because it entails costly monitoring for weeds during the growing season (Mrabet 2008). The input calendars used to calibrate our model can be found in table 2.

We use data from the Chaouia experiment to roughly estimate the probabilities of rainfall events q and yields $y^j(q)$ for $j = \{CT, NT\}$. The region has a long-term average annual growing season rainfall of 308 mm (measured from 1967–2003).[4] Generally, 190 mm of rainfall is required to ensure wheat growth. In the nine years of experimentation in Chaouia, average rainfall was 265 mm. Two of the nine study years were characterized by catastrophic drought as rainfall was well below 190 mm and the crop failed. In two years rainfall was in the vicinity of 190 mm and yields were close to the nine-year average. We consider these years

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[2] We employ masculine pronouns because all household heads in our sample are male.

[3] Where available, NT seeding services cost the same as services for CT seeding, and both are 50% subsidized by the state. Some farmers use less seed with NT due to better seed penetration.

[4] Judging rainfall by a single number is misleading because timing and frequency of rainfall is important. However, to simplify this modeling exercise, we do just that.

Table 2. Best Practices Input Calendars for CT and NT

		$j = \text{Conventional Till}$		$j = \text{No} - \text{Till}$	
	Month	Input	Cost (Dh/ha)	Input	Cost (Dh/ha)
$t = 1$	July	Deep plow	350		
$\hat{a}_1^j$	Oct	Cover crop plow	200	Herbicide	300
	Nov	Seeds and seeder	560	Seeds and seeder	560
		Starter fertilizer	520	Starter fertilizer	520
	Dec	Herbicide	200		
$t = 2$	Feb	Cover fertilizer	250	Cover fertilizer	250
$\hat{a}_2^j$	Mar	Fungicide	285	Fungicide	285
	Mar–Apr	Herbicide or weeding	100	Herbicide or weeding	300
	May–June	Harvest and baling	950	Harvest and baling	950
Total $t = 1$			1830		1380
Total $t = 2$			1585		1785
Total $t = 1, 2$			3415		3165

Note: 8 Moroccan dirhams = ~1 U.S. dollar.

of mild drought. In the other five years, rainfall was well above 190 mm and yields were better than average. We consider these good rainfall years. Based on these data, we initially calibrate our model with a 0.2 probability of catastrophic drought, a 0.2 probability of mild drought, and a 0.6 probability of good rainfall. From there, we increase the probability of catastrophic drought to examine the potential effects of climate change on quasi-option value and technology choice.

In a multitude of field trials, NT has outperformed CT in Morocco, particularly in low rainfall years. In normal rainfall years, yield increases have been less tangible than in low rainfall years; and in catastrophic drought years, yields are essentially zero under either technology (Mrabet 2008). The results of the Chaouia experiment support these general findings. Average yields were identical under NT and CT in catastrophic drought years (0.14 tonne per hectare [T/ha]) and good rainfall years (2.7 T/ha).[5] In years of mild drought, NT generated average yields of 2.6 T/ha compared with 1.9 T/ha under CT. If we assume that farmers can achieve the same yields as agronomists, then NT stochastically dominates CT, and farmers should unambiguously adopt NT. In practice, however, adoption is far from ubiquitous in Morocco and elsewhere (Knowler and Bradshaw 2007; Mrabet 2008). Although this lack of adoption could be for many reasons, here we offer only a few that relate to yields.

A lack of farmer experience with NT may result in lower yields than agronomists achieve, whereas farmers have a great deal of experience with CT. Alternatively, farmers might achieve lower NT yields than those at experiment stations because they are unable to keep crop residues on their fields due to livestock grazing, which results in suboptimal NT yields (Mrabet 2008). It is also possible that farmers perceive additional yield risk associated with using NT because it is an unfamiliar technology and they attach a premium to avoiding that risk (Ding, Schoengold, and Tadesse 2009). Taking a more global perspective, NT yields have not been demonstrated to be greater than CT yields everywhere and under all conditions (Knowler and Bradshaw 2007).

So that within the simulation where NT outperforms CT in mild drought years but CT outperforms NT in good rainfall years, we calibrate our model with NT yields 12% lower than those achieved at Chaouia under both mild drought (2.29 T/ha) and good rainfall (2.38 T/ha). Using these lower NT yields does not alter production costs or quasi-option value, but it dampens the revenue-increasing aspect of NT, which better fits the reality of extremely rare adoption.

Results and Discussion

The total benefit of NT adoption is composed of changes in expected revenue (linear in yield)

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[5] As these yields come from agronomic field trials, harvest occurred even under catastrophic drought. Yields this low, however, would not justify the cost of harvest to profit maximizing farmers.

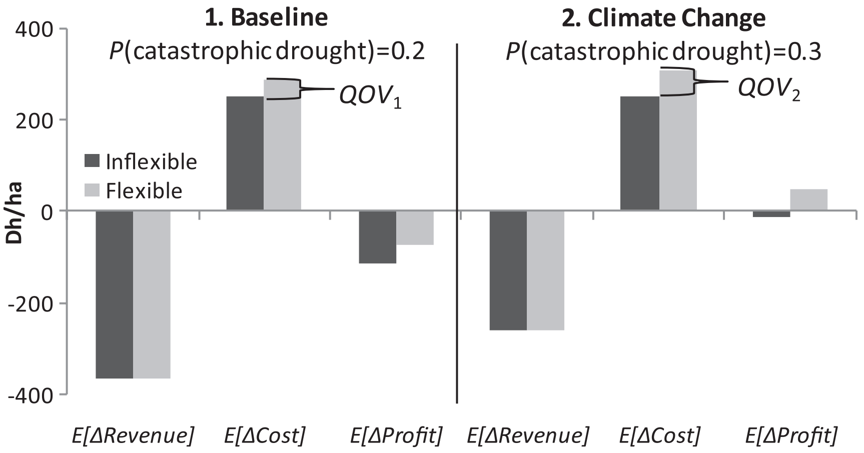

Figure 1. Change in expected revenues, costs, and profits from adopting NT

Notes: E[ΔCost] is expected cost savings, and therefore positive for a change from CT to NT. Eight Moroccan dirhams = ~1 U.S. dollar.

and expected cost savings. Expected cost savings can be further broken down into savings captured by both flexible and inflexible farmers and quasi-option value, which is captured by only flexible farmers. Referring back to equations (3) and (5), we calculate quasi-option value as the difference between CT and NT profits for a flexible farmer, $\Delta E[\Pi_{Flex}]$, less the difference in profits for an inflexible farmer, $\Delta E[\Pi_{Inflex}]$. With the model calibrated as described, a flexible farmer using either technology will abandon his crop under catastrophic drought, and otherwise invest in second period inputs. Therefore changes in expected revenue from NT adoption are the same for both the inflexible and flexible farmer, and quasi-option value can be reduced to the probability of catastrophic drought times the difference in second period input costs between NT and CT, i.e.,

$$(6) \qquad QOV = P(\text{catastropic drought}) \cdot (\hat{a}_2^{\text{NT}} - \hat{a}_2^{\text{CT}}).$$

Under the baseline probability distribution of rainfall described in the previous section (figure 1, left panel), expected revenue under NT is 365 Moroccan dirhams (Dh)/ha ($45/ha) less than under CT. The inflexible farmer saves 250 Dh/ha on production costs, which is not enough to compensate for forgone revenue. The flexible farmer receives an additional 40 Dh/ha of quasi-option value, bringing total cost savings to 290 Dh/ha (a 16% increase). These savings are still insufficient to incite adoption, and the net benefit of NT adoption is negative for both the inflexible and the flexible farmer.

Next we suppose that climate change increases the probability of catastrophic drought to 0.3 and reduces the probability of good rainfall to 0.5 (figure 1, right panel). In this case expected revenue under NT is 262 Dh/ha less than under CT because the probability of good rainfall is lower than in the baseline simulation. Cost savings are still 250 Dh/ha for the inflexible farmer, so he still does not adopt NT. However, the quasi-option value of delayed input use is now 60 Dh/ha, which increases total expected cost savings to 310 Dh/ha (a 24% increase) and total expected benefit of adoption to 48 Dh/ha for the flexible farmer, inciting adoption.

These results demonstrate that the quasi-option value of NT composes a substantial portion of the total cost savings offered by this technology. As climate change makes catastrophic drought more frequent, the quasi-option value of delayed input use can become pivotal in the adoption decision of farmers who frequently abandon their crop midseason.

Closing Remarks

In semi-arid climates like those characteristic of Morocco and the Mediterranean region, catastrophic drought frequently forces farmers to cut their losses by abandoning their crop midseason. Under such circumstances, the more a technology delays input requirements beyond a point when the abandonment decision is typically made, the greater the flexibility the technology offers. In this paper we use a simple model of farmer flexibility to show that as catastrophic drought becomes more likely, the quasi-option value of delayed input use increases and that in some cases quasi-option value could be a critical factor behind technology choice.

Although the revenue-increasing benefits of NT may be difficult for farmers to comprehend, or may be met with apprehension because of uncertainty about whether these benefits will occur on their specific plots, the quasi-option value of NT should be easy to grasp; farmers in dryland agriculture understand catastrophic drought and crop abandonment. It is therefore important that researchers and extension agents account for the quasi-option value of NT when computing the total benefits of adoption and subsequently tout this quasi-option value to potential adopters.

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References

Arrow, K., and A. Fisher. 1974. Environmental Preservation, Uncertainty, and Irreversibility. *Quarterly Journal of Economics* 88(2): 312–319.

Balaghi, R., M. Jlibene, B. Tychon, and R. Mrabet. 2007. Gestion du Risque de Sécheresse Agricole au Maroc [Drought Risk Management in Morocco]. *Sécheresse* 18(3): 169–176.

Barakat, F., and A. Handoufe. 1998. Approche Agroclimatique de la Sécheresse Agricole au Maroc [An Agroclimatic Approach to Drought in Morocco]. *Sécheresse* 9: 201–208.

Chavas, J.-P., P. M. Kristjanson, and P. Malton. 1991. On the Role of Information in Decision Making: The Case of Sorghum Yield in Burkina Faso. *Journal of Development Economics* 35: 261–280.

Ding, Y., K. Schoengold, and T. Tadesse. 2009. The Impact of Weather Extremes on Agricultural Production Methods: Does Drought Tolerance Increase Adoption of Conservation Tillage Practices? *Journal of Agricultural and Resource Economics* 34(3): 395–411.

Fafchamps, M. 2003. *Rural Poverty, Risk, and Development.* Cheltenham, UK: Elgar.

Giné, X., R. Townsend, and J. Vickery. 2009. Forecasting When It Matters: Evidence from Semi-Arid India. Working paper, World Bank.

Knowler, D., and B. Bradshaw. 2007. Farmers' Adoption of Conservation Agriculture: A Review and Synthesis of Recent Research. *Food Policy* 32: 25–58.

Mrabet, R. 2010. Wheat Yield Stability under Contrasting Soil Management Strategies and Crop Rotations in Semiarid Morocco. Paper presented at Agro2010, Montpellier, France.

Mrabet, R. 2008. *No-Tillage Systems for Sustainable Dryland Agriculture in Morocco.* Manuscript. Rabat : Institut National de la Recherche Agronomique.

Nail, E. L., D. L. Young, and W. F. Schillinger. 2007. Diesel and Glyphosate Price Changes Benefit the Economics of Conservation versus Traditional Tillage. *Soil and Tillage Research* 94: 321–327.

Rosegrant, M., X. Cai, S. Cline, and N. Nakagawa. 2002. The Role of Rainfed Agriculture in the Future of Global Food Production. Environment and Production Technology Division Discussion Paper No. 90, International Food Policy Research Institute.

Van Noordwijk, M., G. H. Dijksterhuis, and H. Van Keulen. 1994. Risk Management in Crop Production and Fertilizer Use with Uncertain Rainfall: How Many Eggs and Which Baskets. *Netherlands Journal of Agricultural Science* 42(4): 249–269.