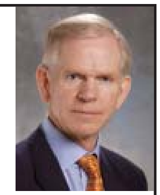
GMO

QUARTERLY LETTER

July 2011



Resource Limitations 2: Separating the Dangerous from the Merely Serious

Jeremy Grantham

"You and I, and our government must avoid the impulse to live only for today, plundering, for our own ease and convenience, the precious resources of tomorrow." Dwight D. Eisenhower, 1961[1]

"[They] would have us believe that there is no cause for anxiety, that reserves [of oil] will last thousands of years, and that before they run out science will have produced miracles. Our past history and security have given us the sentimental belief that the things we fear will never really happen – that everything turns out right in the end. But prudent men will reject these tranquilizers and prefer to face the facts so that they can plan intelligently…" Admiral Hyman Rickover, 1957[2]

"The nation that destroys its soil destroys itself." Franklin Delano Roosevelt, 1937 [3]

Introduction

Last quarter I tried to make the case that the inevitable mismatch between finite resources and exponential population growth had finally shown its true face after many false alarms. This was made manifest through a remarkably bubble-like explosion of prices for raw materials. Importantly, prices surged twice in four years, which is a most unbubble-like event in our history book. The data suggested to us that rarest of rare birds; a new paradigm. And a very uncomfortable one at that. (In general, though, I have tried here not to repeat arguments or data used last quarter.)

This quarter, I would like to focus on the most dangerous parts of the coming shortages. I will try to separate those that, for us rich countries, are merely going to slow down the growth rate of our wealth through rising prices, and those that will do not only that, but will actually be a threat to the long-term viability of our species when we reach a population level of 10 billion. In all cases, poorer countries will be the most threatened. Situations that will irritate some of us with higher prices will cause others to starve. Situations that will cause some of us to go hungry will be for others a real disaster, and I believe this, unfortunately, will not be in the dim and distant future.

Obviously, experts have written books on subtopics that I reduce to one sentence. I might add that these books and a myriad of articles by these experts – who have decades of experience – absolutely do not agree with each other. In fact, they differ probably as widely as any scientific topic around, often by a literal order of magnitude and often with heat. Unlike many scientific differences, some of those concerning our resources in the long run may actually be a matter of life and death. I have tried to start from a weighted-average position and then have allowed for a safety margin tilted in favor of protecting our long-term well-being. By definition, plenty of experts will disagree with each statement made here. My hope is that "our" experts are those that are more rigorous, intelligent, and protective.

Capitalism does not address these very long-term issues easily or well. It seems to me that capitalism's effectiveness moves along the spectrum of time horizons, brilliant at the short end but lost, irrelevant, and even plain dangerous at the very long end.

1 Dwight D. Eisenhower, Farewell Address, January 17, 1961. (Also see, Jeremy Grantham's "I Like Ike: A Powerful Warning Ignored," January 14, 2011; located in the Library of GMO's website, registration required.)

2 Admiral Hyman Rickover, "Energy Resources and our Future," remarks delivered in 1957.

3 Franklin Delano Roosevelt, Letter to all State Governors on a Uniform Soil Conservation Law, February 26, 1937.

Summary

- We humans have the brains and the means to reach real planetary sustainability. The problem is with us and our focus on short-term growth and profits, which is likely to cause suffering on a vast scale. With foresight and thoughtful planning, this suffering is completely avoidable.
- Although we will have energy problems with peak oil, this is probably an area where human ingenuity will indeed eventually triumph and in 50 years we will have muddled through well enough, despite price problems along the way.
- Shortages of metals and fresh water will each cause severe problems, but in the end we will adjust our behavior enough to be merely irritated rather than threatened, although in the case of metals, the pressure from shortages and higher prices will slowly increase forever.
- Running out completely of potassium (potash) and phosphorus (phosphates) and eroding our soils are the real long-term problems we face. Their total or nearly total depletion would make it impossible to feed the 10 billion people expected 50 years from now.
- Potassium and phosphorus are necessary for all life; they cannot be manufactured and cannot be substituted for. We depend on finite mined resources that are very unevenly scattered around the world.
- Globally, soil is eroding at a rate that is several times that of the natural replacement rate. It is probable, although not certain, that the U.S. is still losing ground. The world as a whole certainly is.
- The one piece of unequivocal good news can be found in the growth of no-till farming. In no-till, the residue of the previous crop is left on the ground and new seeds are planted without plowing. This technique reduces erosion by around 80%, reduces fertilizer run-off, preserves moisture, improves the soil (and, quite possibly, the quality of the food), and reduces the emissions of heat trapping gasses.
- The growth of no-till has been very rapid in South America, rapid in the U.S. (which is now at 35%), and moderate in many other developed countries. But it is used on only about 5% of farms globally.
- Overall, the best farms will have no erosion problems but, on average, soil will continue to be lost across the globe. Together with increased weather extremes and higher input prices (perhaps much higher), there will be increasing problems in feeding the world's growing population.
- In particular, a significant number of poor countries found mostly in Africa and Asia will almost certainly suffer from increasing malnutrition and starvation. The possibility of foreign assistance on the scale required seems remote.
- The many stresses on agriculture will be exacerbated at least slightly by increasing temperatures, and severely by increased weather instability, especially more frequent and severe droughts and floods.
- These types of slow-burning problems that creep up on us over decades and are surrounded by a lack of scientific precision hit both our capitalist system and our human nature where it hurts.
- Capitalism, despite its magnificent virtues in the short term – above all, its ability to adjust to changing conditions – has several weaknesses that affect this issue.
  - It cannot deal with the tragedy of the commons, e.g., overfishing, collective soil erosion, and air contamination.
  - The finiteness of natural resources is simply ignored, and pricing is based entirely on short-term supply and demand.
  - More generally, because of the use of very high discount rates, modern capitalism attributes no material cost to damage that occurs far into the future. Our grandchildren and the problems they will face because of a warming planet with increasing weather instability and, particularly, with resource shortages, have, to the standard capitalist approach, no material present value. [4]

4 An expanded discussion on the failings of capitalism will be in next quarter's letter. In addition, a discussion on the current market, including any investment implications from this piece, will be posted in two weeks.

Perspective

With hindsight, there are a few additions and qualifications I would like to make regarding my letter on resources of last quarter. I will start with an overview of the prospects for our collective well-being: there is nothing about the resource limitation problem that we cannot resolve. We have the brain power and, especially, the inventiveness. We have some nearly infinite resources: the sun's energy and the water in the oceans. We have some critically finite resources, but they can be rationed and stretched by sensible, far-sighted behavior to fill the gap between today, when we live far beyond a sustainable level, and, say, 200 years from now, when we may have achieved true long-term sustainability. Such sustainability would require improved energy and agricultural technologies and, probably, a substantially reduced population. With intelligent planning, all of this could be reasonably expected. A population reduction could be arrived at by a slow and voluntary decline (perhaps with some encouragement of smaller family size achieved, for example, through greater education). Such a reduction might leave us with a world population of anywhere from 1.5 billion to 5 billion, depending on the subtleties and interactions of many complicated variables. We would then be in long-term balance with our resources, including what will remain by then of our current biodiversity, which will hopefully be as much as one-half to three-quarters of what we have today.

The problem is not what we are capable of, but how we will actually behave. The wasteful status quo has powerful allies in the present corporate and political system. We do not easily accept bad news, nor do we easily deal with long-horizon problems. As mentioned last quarter, we are not particularly good with numbers, especially when it comes to probabilities, compound growth, and discount rates. We have a capitalist system that reflects our weaknesses; one that is fine-tuned only for the present and immediate future. Because of these factors, we will probably wait to deal with the obvious problems of living well beyond our means until the signs are powerful and clear that we must change; until, that is, it is basically too late. Too late in the sense of failing to protect much of what we enjoy and value today. Too late to have avoided plundering our grandchildren's resources. It's a shame, but it's the bet a well-informed gambler, observing from another planet, would probably make. It's why, in the environmental business, which shares many of the same problems with resource management, it can be honestly said that there are old environmentalists and optimistic environmentalists, but no old, optimistic environmentalists. I'm probably as close as you're going to get. The following argument looks at the resource problems we face in order of declining optimism. I think what follows is reasonable rather than apocalyptic. And, there is one remarkable piece of good news – the steady rise of no-till farming. In this, the developed world at least seems to have truly lucked out! However, with the pressures of short-term profit maximizing, there is some chance that we will not capitalize on our good luck.

A Possible Hierarchy of Problems

1. Energy

The transition from oil will give us serious and sustained problems. We passed peak oil per capita long ago and we are within 30 years, possibly within 10, of peak oil itself. The price will be volatile beyond our wildest dreams (or nightmares), and the price trend will rise, although at times this will be difficult to discern through the volatility. Transportation will be difficult in general and air transportation in particular. But behind oil, there is a relative plenty of natural gas and coal, which can, although with cost and difficulty, be substituted for oil. Even with coal and gas, however, we are dealing with only many decades of supply, not centuries. But beyond hydrocarbons there really is good news. Within 50 years or so, I believe we will have made spectacular progress in the science and engineering of solar, wind, tidal, and other energy sources, together with storage. One simple storage management idea for the nearer term, for example, is that every electric car would have two easily-exchangeable battery packs, with one in the garage, storing solar from your roof while you drive to work. Whenever possible, all such batteries would be attached to an intelligent grid that would be able to raid batteries or deposit into them, giving massive flexibility by today's standards. It is also possible (although, unfortunately, I believe improbable) that we will have a new, large-scale burst of activity in nuclear fission, perhaps stimulated by some technological improvements. Further out, completely new forms of commercial energy are likely, perhaps from nuclear fusion of some kind, or perhaps from something completely off of our current radar screen. This is where my optimism comes in, for I believe that in 50 or so years

– after many and severe economic and, possibly, social problems – we will emerge with sufficient, reasonably-priced energy for everyone to live a decent life (if we assume other non-energy problems away for a moment) even if we don't radically improve our behavior and make true sustainability our number one goal. In other words, current capitalist responses to higher prices should get the job done. We should realize, though, that reasonably-priced does not mean the nearly give-away prices of oil in the post war period, which serves as a real testimonial to the failure of standard free-market practices to recognize that a vital resource being finite changes everything in the long run. "Reasonably-priced" fuel would be where prices rise steadily faster than the CPI rather than ruinously so.

2. Metals

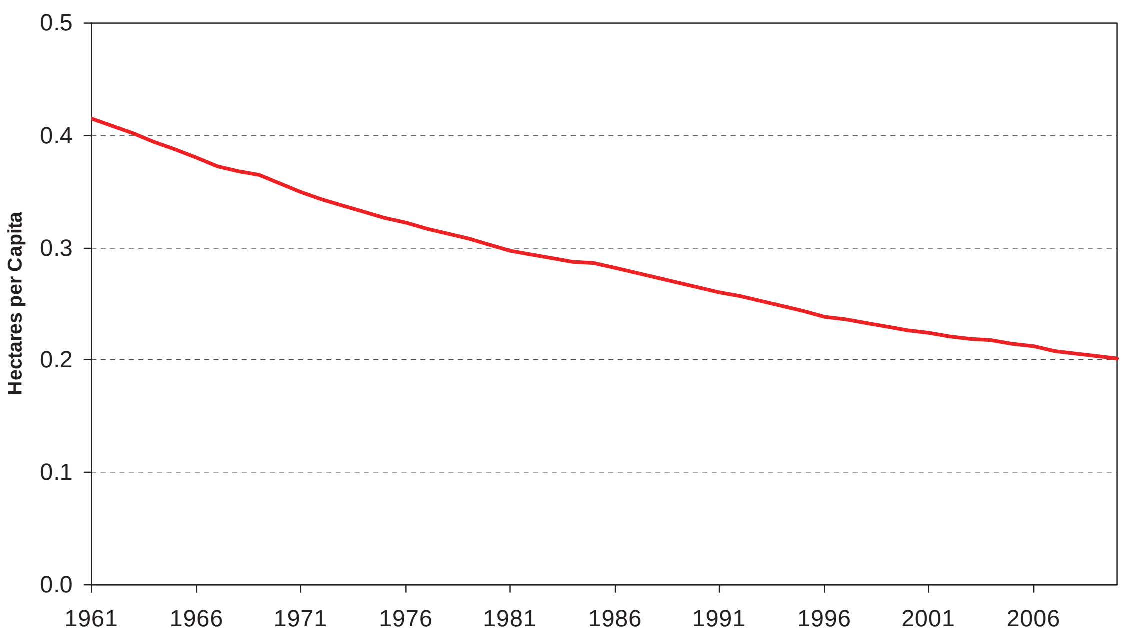
Metals are, of course, a bigger long-term problem than energy. They are entropy at work ... from wonderful metal ores to scattered waste. Even the best recycling will have slippage. Entropy is impressive; everything really does run downhill, iron really does rust. So our future will undoubtedly be increasingly constrained, particularly if our population and its wealth both grow steadily. Eventually, the growth of both population and wealth will be limited and possibly even stopped by a lack of metals, but that should, with luck, be a long time away. If we respond to increasing price pressures, as I'm sure we will, with a greater emphasis on quality and small scale along with an increasingly sensible and non-wasteful lifestyle, then we can push these serious constraints out for well over a hundred years. This is assuming, once again, no radical shift in attitudes and behavior other than those elicited by higher prices.

3. Agriculture

The trouble really begins with agriculture. This is the factor that I believe almost guarantees that we end up with a world population between 1.5 and 5 billion. The only question for me is whether we get there in a genteel, planned manner with mild, phased-in restraints, or whether we run head down and at considerable speed into a brick wall. There are three particular aspects of agriculture where the shoe pinches the most: water, fertilizer, and soil. All three must be seen in the context of a rapidly growing population. To set the scene, Exhibit 1 shows arable land per person. Unlike us, suitable land for agriculture has not increased since farming started some 10,000 years ago. In fact, with our help it has declined considerably, perhaps by as much as half or more!

Exhibit 1

World Hectares of Arable Land per Capita



Source: United Nations Food and Agriculture Organization, U.S. Census Bureau As of 12/31/10

A. Water

There is no doubt that water shortages will be a source of economic and social trouble forever. Countries will rattle sabers or, worse, go to war over access to river waters. That is certain. But viewed as a problem for the U.S. or for the planet as a whole, it does not seem to be a game stopper. The surface of our planet is, after all, mostly water. For our direct use and for our crops, we need a derisorily small fraction of Earth's supply of water. The entire planet's current wasteful use of fresh water is equal to only 80% of the flow of the Amazon. We also use our existing supplies of renewable <u>fresh</u> water with desperate inefficiency and wastefulness. As prices rise, we can save not just a few percent but a great majority of our water by growing the right things in the right places and by sensibly sharing and recycling the resource. Further out, with likely sources of reasonably cheap energy, we could supplement our supply with desalinated ocean water for coastal populations. Other than shifting crops, the main effect on agriculture will be a steady increase in the cost of water as we move slowly to recognizing the real costs of supplying water to farming. However, come back in 50 or 100 years and we will, I believe, have been persistently irritated by water problems but never seriously threatened as a species.

For farming productivity, one of the greatest irritants for the next 50 years will be the depletion of fossil water: the great underground lakes of fresh water that receive little or no replenishment by rainfall. By bad luck, such vast deposits underlie and make possible some of the planet's great bread baskets, including parts of the U.S. plains, parts of the Northwest of the Indian subcontinent, and parts of Northeastern China. If these very large areas are to stay in production, and they will certainly be needed, then major water transfer systems – canals of 500 to 2,000 miles in length – will have to be developed and the water taken from elsewhere. But even this, although it spells investment and environmental troubles in a big way, sounds ultimately doable, at a price. (The nastiest near-term problem of this kind will be in Yemen, where there is almost total dependence on underground fossil water, which is beginning to run out as I write!)

B. Fertilizers

Fertilizers are, I believe, less tractable. The three major macro nutrient fertilizers are the well-known N-P-K of lawn fertilizer: nitrogen, phosphorus, and potassium. Nitrogen, the most urgently needed of the three <u>every year</u>, is found in the greatest quantity so is happily the least problematical. Many crops, such as soya and alfalfa, supply or "fix" nitrogen for our main cereal production. Bioengineering is likely to increase this ability as well as broaden the range of plants that are able to do this. Electrical storms provide large quantities of nitrogen fertilizer out of the very air itself. (This provides about 5% of all nitrogen fixation, while modern agriculture accounts for about 50%). More dependable man-made, or rather man-processed, nitrogen fertilizer is very efficiently made with natural gas, which is being found, fortunately, in increased quantities in many different regions of the world. Several of these regions – notably the U.S. and China – are major grain producers. Therefore, if we don't go out of our way to waste our natural gas on less important products, we should be fine at least through this century. Nitrogen is the largest component of air and just needs energy to be converted into fertilizer. So, longer-term availability of nitrogen-based fertilizer is, as with water, about cost, not availability. But, starting with today's almost ridiculously low prices for natural gas (20% BTU equivalency of oil – just about the lowest in history), farmers should count on seeing increasing multiples of the price for nitrogen fertilizer in the next 10 to 15 years.

Potassium (potash)

Potassium is in a less favorable situation. Today's known resources are shown in Exhibit 2. Although it is found widely, very large and high grade (i.e., cheap) deposits are concentrated to quite a remarkable degree in two areas: one in Russia and Belarus and the other, happily for North America if we all stay friendly, in Canada. Unless there is considerable cartel-like behavior, which is certainly not unheard of these days with some commodities, then we have plenty of time to study the very long-term shortage problem. Luckily for us, potassium is a generously supplied element in the Earth's crust.

Exhibit 2

World Potash Production and Reserves

(thousands of metric tons)		
	2010 Production	Reserves
United States	900	130,000
Belarus	5,000	750,000
Brazil	400	300,000
Canada	9,500	4,400,000
Chile	700	70,000
China	3,000	210,000
Germany	3,000	150,000
Israel	2,100	40,000
Jordan	1,200	40,000
Russia	6,800	3,300,000
Spain	400	20,000
Ukraine	12	25,000
United Kingdom	400	22,000
Other Countries	-	50,000
World Total (rounded)	33,000	9,500,000

Source: U.S. Geological Survey As of 12/31/10

Nevertheless, it is worth pointing out that both potassium and phosphorus (phosphates) have some characteristics that we are not accustomed to dealing with in our neat and short-term-oriented investment world. They are characteristics that make energy problems seem trivial because energy can be extracted in so many different ways.

- Potassium and phosphorus cannot be made. They are basic elements.
- No substitutes will do. Both potassium and phosphorus are required for all living matter, animal and vegetable. Most notably, us. We humans are, for example, approximately 1% phosphorus by body weight.
- Modern high-production, single-crop agriculture today is very dependent on finite mined resources, which, if used wastefully, could easily cause a severe problem within 50 years and, if used sensibility and sparsely, could last for perhaps 200 years. And then what? You must recycle and farm super intelligently, as if your life depended on it. And it will.

Phosphorus (phosphates)

The reserve situation for phosphorus is shown in Exhibit 3. Admittedly, there are big arguments over reserves of both potash and phosphates because neither has been explored as comprehensively as have oil reserves. Here, too, we are quite lucky because the reserve life gives us time to plan sensibly for the rest of our lives (as a species, that is). But here again, the reserves are not evenly distributed and this time the skew is more, shall we say, interesting. It is thought that between 50% and 75% of the reserves are in Morocco and "associated" Western Sahara. Morocco's share of phosphates makes Saudi Arabia's share of oil look like small potatoes and, in the end, who values heating more than eating?

The existing high quality reserves shown in Exhibit 3 look, superficially, very satisfactory. There are reserves equal to 369 years of current production. Even allowing for 2% growth to help maintain productivity, these reserves would not run out for about 200 years. But, without Morocco and at 2% growth, reserves would be totally depleted in under 50 years. So with or without new reserves being located, some substantial gamesmanship should be expected within a few decades. Or, put it this way: if the phosphates were in my kingdom, I would try to make some hay.

Exhibit 3

World Phosphorus Production and Reserves

(thousands of metric tons)	2010 Production	Reserves
United States	26,100	1,400,000
Algeria	2,000	2,200,000
Australia	2,800	82,000
Brazil	5,500	340,000
Canada	700	5,000
China	65,000	3,700,000
Egypt	5,000	100,000
Israel	3,000	180,000
Jordan	6,000	1,500,000
Morocco and Western Sahara	26,000	50,000,000
Russia	10,000	1,300,000
Senegal	650	180,000
South Africa	2,300	1,500,000
Syria	2,800	1,800,000
Togo	800	60,000
Tunisia	7,600	100,000
Other Countries	9,500	620,000
World	176,000	65,000,000
World excluding Morocco	150,000	15,000,000

Source: U.S. Geological Survey As of 12/31/10

The long-term phosphorus supply is probably the trickiest and most threatening issue to date. There may be a lot of lower-grade reserves that have not been listed or even looked for. (Why pay money to do that when there are decades' worth of low-cost, very high-quality reserves?) But there may not be. We are currently ferreting out as much of the limited data there is available. (Data on this and the many other conundrums raised in several of the topics discussed in this letter will be relayed from time to time as we can dig them out.) Serious scientific experts at this point are mostly "supposing" that, as is the case with many other resources, there are more, often much more, lower-quality reserves that are currently unrecorded than there are known high-quality reserves. But this is not always the case. The U.K., for example, had a lot of high-quality anthracite and bituminous coal reserves, which propelled them into the Industrial Revolution, but today all of its anthracite is gone, most of its bituminous is gone, and there are no very large reserves of brown coal or lignite as there are, for example, in Germany.

Most, if not all, of the potash and phosphate deposits are associated with former oceans or salty seas, or that is believed by many to be the case. Well, if you wanted to be pessimistic, you could argue that you either have a dried up former ocean due to the ground rising over aeons, or you don't. Perhaps you don't have masses of smaller dried up bodies of water, which normally would be salt-free. In any case, we are all speculating at this point. Despite its potential importance, reliable data is just not available.

Let us imagine for a minute what might happen in 50 or 150 years when the last affordable phosphorus is delivered and Morocco is, quite sensibly, charging thousands of dollars a ton for the last one-third of its resources. We might be developing offshore recovery from the continental shelf at a little less than Morocco's price, but still a gaspingly high price that would not be even remotely affordable by poorer countries. But mostly we would be recycling, a word with which our grandchildren will get awfully bored. It's how crops were grown in the pre-commercial fertilizer age, at least wherever farmers could not engage in slash and burn and move on. Chinese farmers in particular successfully maintained the productivity of their fields for thousands of years by almost religiously recycling: off to the town market with two buckets of beans and back with two buckets of "night soil." Human and animal waste, as well as vegetable waste, was scrupulously reused. Countries that pushed their production or were not so careful in recycling depleted their soils. Eastern Europe in particular had recurrent crop failures and starvation as late as the 1880s. And, we could do it better now than the Chinese did in the old days, for science has marched on. We have learned to reduce nutrient loss considerably in the last 50 years. There is also much more that we could do, and we had better get moving: the last time the world depended mainly on recycling, the global population was a mere one billion. The next time it may be 10 billion – cross your fingers it's not more. Could a world based on recycling nutrients, even one supplemented by very high-priced remnants of our mined fertilizer resources, really feed 10 billion? Or even 5 billion? I think the answer is certainly no if we do not get our act together in the next very few decades. Even then, it is more likely that true sustainability will be a much lower number than 10 billion.

C. Soil Erosion

Finally, there is the real bugbear: soil erosion. The Earth is a wonderful place that obligingly creates new soil from bedrock, using the wear and tear of weather plus bacterial and microbial action. Perhaps even more remarkably, this new soil arrives with a good complement of phosphorus and potassium. This is pretty good treatment from a very generous planet. Before humans appeared, the rains would dissolve and wash away the soil and its associated nutrients just as fast as it was produced, but no faster. That's a pretty neat balancing trick too. We can record the steady, modest rate of erosion in ancient lake beds. Humans, alas, with their tree lust, initially for heat and shelter and later for arable space and fertilizer (burning the forest sheds its store of fertilizer and other nutrients), began to cut forests down so fast that the erosion rate increased. Nothing increases erosion and net nutrient loss faster than deforestation. (And, ironically, nothing encourages deforestation like erosion, because erosion decreases productivity and, hence, increases the pressure to bring on new land to fill the gap in a rather vicious feedback loop.) As our population grew, the forests were thus diminished in size, and the arable land increased. Even plowing savannahs, where trees had seldom or never grown, increased erosion by a large multiple. Sometimes these factors would accumulate with predictable results. In Panama, for example, it is common to see very hilly land that was once totally forested being used for cattle grazing. The cattle create paths that form gullies that funnel the tropical rains, which in turn denude whole hillsides in a few decades.

What the precise situation is today is hard to tell: First, erosion varies widely from region to region by type of soil and agricultural practice. Second, its measurement must also be difficult, for scientists have widely different views as to the best methodology. At one extreme, the reports are almost terrifying. A group of scientists from Cornell University writing in Science magazine[5] summarized their findings as follows: "Soil erosion is a major environmental threat to the sustainability and productive capacity of agriculture. During the last 40 years, nearly one-third of the world's arable land has been lost by erosion and continues to be lost at a rate of more than 10 million hectares per year ... In the U.S. an estimated 40 billion tons of soil ... are lost each year." Unfortunately, Cornell's Agricultural School has high standing in its field – reading their summary, one's instinct is to say, "Well that's it then. In a hundred years, everyone starves." Fortunately, there are also those at the other extreme who think we'll muddle through just fine, at least in the U.S. And, as we will see, the rise of no-till farming has the potential to help a lot.

The brief nitty-gritty on erosion and replacement is that somewhere between 50 and 1,000 years is needed to naturally replace one inch (25mm) of subsoil, depending on local conditions and who is doing the research. Different soil has different weights, but averages about 5 tons per acre per millimeter or 125 tons per acre per inch. Therefore, the natural replacement rate is equal to 2.5 to 0.125 tons per acre per year, rather than the 5 tons per acre per year that the U.S.D.A. has been using as an acceptable erosion rate. To state this very conservatively, current U.S. soil losses are very probably higher than natural replacement and possibly considerably higher. In Australia too, where records go back into the nineteenth century, it is also clear that more than 70% of arable land has been degraded to some considerable degree. For the planet as a whole, soil losses are certainly higher than replacement, and for some areas, notably in Africa, they are disastrously higher.

5 David Pimentel, et al., "Environment and Economic Costs of Soil Erosion and Conservation Benefits," *Science*, New Series, Volume 267

Further offsetting any of the more favorable data in the U.S. is a recent report from Iowa State University.[6] The report, which claims new accuracy levels, holds that typical erosion is not the issue, but that the rare extreme storm can cause one to several years' erosion in a single night as new gullies form in a way totally unlike those that form during regular rain storms. These outlier storms have unfortunately become much more common globally in recent years, with formerly rare weather events having become more frequent as a consequence of a warming climate.

History of Erosion

We now know that population density in the Fertile Crescent and some of the other centers of early civilization often dropped precipitously as their soils, due mainly to plowing, eroded. By the time they were finally disposed of by invaders, they were often shells of their former might with tiny fractions of their original populations left. North Africa was home to empires such as Carthage, which were powerful enough to challenge Rome and, in other cases, fertile enough to help feed Rome, which was the case of ancient Libya and Tunisia. Most of this territory has lost the great majority of its former agricultural capacity. Ancient Greece, Central Italy under the Romans, Syria, Iraq, and many others all suffered from the effects of subsoil erosion over a period of one thousand or more years, thus limiting their populations and reducing their economic and military power. In its later years, Rome, once at the center of fertile plains, abandoned farms everywhere and was totally dependent on imports from Egypt and Syria. Syria's history is one in which whole cities, with their dozens of surrounding villages, were later completely abandoned to the desert as their soil disappeared due to unsustainable agricultural practices. Fifteen hundred years ago in the Americas, civilizations such as the Mayans overtaxed their soils and provably lost enough soil to make it impossible to reliably feed their peak populations. (Two readable books for the summer that cover this topic in detail are: Dirt: The Erosion of Civilizations, by David R. Montgomery and Collapse: How Societies Choose to Fail or Succeed by Jared Diamond.) The academic study previously cited,[7] claims the loss of one-third of our soil globally in just a few decades. It is easy to believe that since the beginning of human history it might be fully one-half, or even more.

The history of soil erosion bringing ancient empires down might have served as a powerful warning, but it does not seem to have done so. Since Colonial times, the U.S. is thought to have lost one-third to one-half of its topsoil, and today is still losing at a rate faster than replacement, although at a recently much-reduced rate. Yet, as recently as the 1920s, the 1930s of Dust Bowl fame, and the 1940s, U.S. farms were eroding at disastrous rates – well over 10 times replacement, despite the historical warnings.

Globally, the situation has been, and remains, much worse than in the U.S. It is not clear what it will take to drive home the message that erosion is perhaps the single largest threat to our long-term well-being. It is certainly one of them. But erosion is insidious in that it has always crept up very slowly on both ancient and modern civilizations alike. Syrian farmers in 100 A.D. were concerned with supplying Rome in a year when prices were high. We can be sure that slow (even if steady) losses of productivity seemed to them to be academic abstractions in contrast. Today, what we might call the tyranny of the discount rate guarantees the same behavior. Damage far out has little value, and there is no adjustment factor for damage to all of us collectively. Only the gain of the individual or the corporation appears in the spreadsheet. This is a severe, perhaps even fatal, flaw in traditional free-market capitalism, and there are others that relate to this general topic: capitalism has not easily handled the finiteness of our resources. This topic – deficiencies in capitalism – is a big one and I will try to do it justice next quarter. For now, to link the current topic of erosion with that of next quarter's on capitalism, I offer a brief story of the Devil and the Farmer.

The Devil and the Farmer

The Devil, disguised as an innocent agent of a large agricultural company, arrives at a typical Midwestern farm. He has come to suggest to the farmer that he engage in more aggressive farming, and he comes, as usual, with a contract. The contract, if signed, pledges the farmer to farm aggressively and pledges the Devil to guarantee that the farmer's profits will be multiplied five-fold. But, as always, there is a catch: Footnote 23 is a clause that informs the farmer

6 Craig Cox, Andrew Hug, and Nils Bruzelius, "Losing Ground," April 2011; http://static.ewg.org/reports/2010/losingground/pdf/losingground_report.pdf
7 Ibid.

that squeezing out maximum short-term output will result in the loss of just 1% per year of his soil. The Devil's deal is dangerously reasonable, and therefore I would guess that 90% of farmers would feel that their families' well-being requires that they accept it. The Devil has included a spreadsheet that <u>accurately</u> lays out the profits and also lays out the steady decline in the soil's productivity and, fiendishly, <u>does it honestly</u>. By the end of the 40-year contract, the farm's productivity is down by barely 5%, and the farmer's net financial gains are enormous.

So successful has this period been that the farmer re-ups for another 40 years. Once again, the Devil does not cheat. By the 80-year mark, the soil depth after some natural replacement is almost precisely half of its year 1 level (and, remember, it also lost one-third to one-half of its soil on average in the first 150 years of farming), but the farm has prospered enormously. And, even after the soil loss, it is still by no means particularly sub-average because it turns out that <u>all of the local farmers have made the same deal</u>. All of their productivities have dropped by 20% to 25% but, because of global pressures on grain prices, the deal still looks attractive. The spreadsheets, which have not lied in the past, still accurately and honestly show how profitable it will be for great-grandson and all of his neighbors to re-up yet again. In this way, by always adopting the plan with the optimal present value and by following strict capitalist principles, the Midwest and the planet marches off the edge of the cliff, as farmers, prosperous almost to the very end, are finally overwhelmed by armies of starving city dwellers!

(Note: Appendix 2 shows the back-up material. It is not even close. Normal farmers, using any reasonable discount, would sign and re-sign until soil and productivity go to zero!)

Finally, the Good News

So as not to end too gloomily, I have saved the best news for the end; news so good that Cornucopians can jump for joy and gloomy Malthusians can think "What undeserved luck!" Most huge improvements in anything take equally huge investments of time, energy, and capital. This one, which reduces erosion rates from way over sustainability to acceptable levels, requires very little except a willingness to change one's ways, a characteristic not always in great supply in any group, including farmers. No-till farming, developed in recent decades has, after a slow start, been spreading very rapidly in South America. It is now used in more than 50% of all arable land there, which, given the heavy rains in much of the area, is just as well. In the U.S., the adoption of no-till has very recently accelerated and it now accounts for more than 35% of farmland according to the U.S.D.A. In general, it is growing elsewhere, albeit slowly, and hardly at all in Africa. The bad news is that globally, despite its advantages, it makes up only a 5% share of grain production. Just as it sounds, <u>no-till leaves the crop residue on the field</u> and the following year, instead of plowing up the ground, a rotating wheel pierces the ground every few inches and plants a seed, sometimes together with a precisely measured dose of fertilizer. After a few years, the mat of ground cover massively reduces the erosion caused by heavy rains: the average academic study reports more than an 80% reduction, with the highest being 98% and the lowest 50%. In one fell swoop, the erosion problem can be effectively resolved.

Protecting the soil may be the biggest single advantage of no-till, but there are several other important ones. When soil is washed or blown away, it is the very top soil that goes, and this is the soil that carries much of the nutrients that have been added at no small cost. About one-third of the fertilizer is wasted. This was an irritant when potash was $175 a ton five years ago. At the more recent price of $420 a ton, it is a serious saving – enough to get farmers' attention. With no-till, there are incremental nutrients in the accumulated stubble, which further reduces costs and, more importantly, reduces the load on critical limited fertilizer resources.

Water retention in the soil also greatly increases because the effects from full-scale plowing, which exposes the moist soil to the sun, are mitigated by no-till. When rain is plentiful and evenly spaced, there is little difference between the two systems in this respect, but when rains are scarce or there is full-scale drought, the extra moisture protected by the ground cover can make a big difference to productivity. So life is easier for the soil, whether it is a flood or a drought; a particularly compelling case in these days of increased weather instability.

Finally, the quality of the relatively undisturbed soil improves as the number of microbes, bacteria, fungi, and other living critters steadily multiplies. This in turn arguably increases the carbon density of the soil and definitely further increases the water retention capacity and the amount of micronutrients, which, under full plowing, basically fall to zero. It is widely believed that micronutrients make food healthier and that their chronic absence in modern food has not been healthy for us, molded as we are by tens of thousands of years of eating more complicated foods.

All in all, no-till is like a gift from Ceres and single-handedly would remove or long postpone most of our long-term productivity problems. With no-till, productivity typically drops slightly in the first few years, but then slowly increases. Conversely, with high-erosion plowing, it slowly decreases, with potentially severe consequences over very long periods. Another disadvantage of no-till is that it requires more insecticide, especially in the first few years, which has environmental and financial costs. Researchers, though, increasingly believe that most of this increase can be removed by fine-tuning crop rotation, cover crops, and other "engineering" tricks. The bottom line seems to be that if we adopted no-till globally for a great majority of our grain crops, the only serious threat to agricultural productivity would be from the very long-term shortage of mined fertilizers, with even that threat much postponed. Additional efforts with soil enhancement and full-scale organic farming could further improve fertility and lower the need for "outside" fertilizer, but that is a topic too complicated and controversial to be covered here.

Conclusion

None of this changes the ultimate equation that we have a finite carrying capacity. As the population continues to grow, we will be stressed by recurrent shortages of hydrocarbons, metals, water, and, especially, fertilizer. Our global agriculture, though, will clearly bear the greatest stresses. It may have the responsibility for feeding an extra two to three billion mouths, an increase of 30% to 40% in just 40 years. The availability of the highest quality land will almost certainly continue to shrink slowly, and the quality of typical arable soil will continue to slowly decline globally due to erosion despite increased efforts to prevent it. This puts a huge burden on increasing productivity. Such increases have to contend not only with thinner soils, but also with increasing climate instability, rising costs of all inputs, and long-term availability limitations of fertilizer. In a way that has not applied to the last one or two hundred years but certainly did to many ancient civilizations, we will need to protect and nurture our resources – particularly our farms – if we do not intend to follow them into sand and rocks and depopulation. Encouraged by higher prices, we will become more frugal and more sensible and stretch out our resources, buying us more time for a natural decline in population to eventually bring us into balance. (Leading candidates for greater frugality in grain consumption, for example, would be reduced meat consumption and the banning of the use of quality farmland to produce gasoline substitutes. The U.S. ethanol program is, on a global level, a callous trade-off between unnecessary help to U.S. farmers on the one hand and increasing malnutrition and outright starvation in some of the poorest countries on the other hand.)

Here, the discussion is about the pain and time involved in getting to long-term sustainability as well as trying to separate the merely irritating from the real, often surreptitious, threats to the long-term viability of our current affluent but reckless society. The moral however, is clear. As Jim Rogers likes to say: be a farmer not a banker – the world needs good farmers! I might add: or become a resource efficiency expert and help the world save some of them for our grandchildren. Farming will be a satisfying and enriching experience if, on a global basis, we rise to the long-term agricultural challenges. And, if good old short-term profit maximizing continues as it did for the Syrian, Greek, and Roman farmers before us, then at least today's farm owners will go down with the ship, travelling in first class.

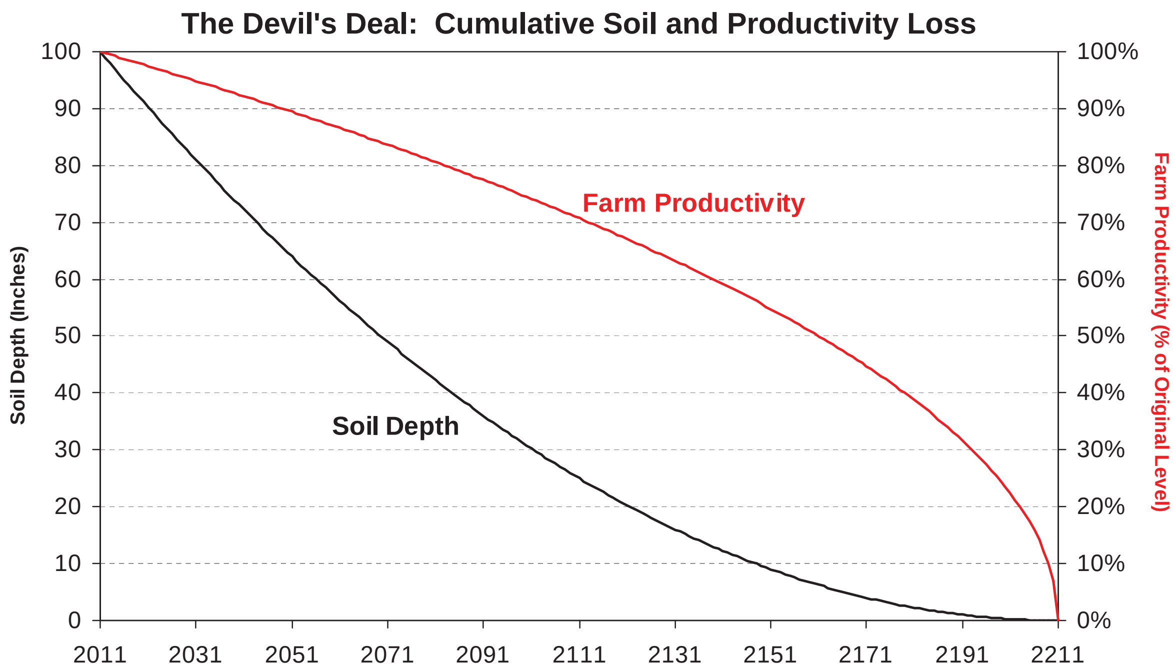
Appendix 1: Malthusians and Cornucopians: the Ehrlich-Simon Bet

While still on the topic of resources, there are a few points I'd like to make on the subject of the famous bet made between Paul Ehrlich and Julian Simon in 1980, which is so often mentioned by opponents of any ideas regarding resource limits. They have been called Cornucopians, which I think is a great term for them. Ehrlich believed that we were beginning to run out of resources; we might call him a Malthusian. He reflected the Club of Rome's thinking and the famous book entitled *The Limits to Growth*.[8] Simon on the other hand, who worked at the Cato Institute for many years, was a classic super-Cornucopian: everything will always be fine because of our species' boundless resourcefulness; population increases are to be welcomed because they cause growth, which in turn stimulates invention so that there will always be plenty. The Cato Institute generally supports any theory that will result in less government and fewer restraints on corporations. (They were grubstaked by the Koch family, they of the hydrocarbon empire, who, not surprisingly, profoundly agree with those beliefs.) The argument that mankind might seriously endanger the long-term productivity of the planet by wasteful overconsumption or by unnecessarily large emissions of carbon dioxide is a dangerous "idea" for libertarians and Cornucopians (we might, I think, reasonably call such things "facts") that might open the door to regulation. Ergo, the facts must be disputed. And every argument along the way, large or small, must be grimly defended, especially the ideal of limitless growth.

And defend it Mr. Simon did, and very effectively. He engaged Ehrlich in a bet on this topic, which he famously won, and the Cornucopians have never let anyone in this field forget it. The essence of the bet was that Ehrlich believed that compound growth could not be sustained in a world of finite resources, and therefore the real price of raw materials would rise. Simon argued that, regardless of the rate of growth, real prices would fall. Of course, the spirit of this bet has no time limit – 40 years is better than 10, and 100 is better than 40. But a bet like this between humans of middle age is one that both would like to collect on. So, the bet was set at 10 years and five commodities[9] were chosen by mutual agreement. Here again, all commodities would have represented the spirit of the bet better than five, but five was easier to monitor. Simon won all five separate bets fair and square at the 10-year horizon. But let's admit that this is a very unsatisfactory time period for the rest of us who are really interested in this contest of ideas. So, let's take an equally arbitrary but much more satisfactory bet: from then, 1980, until now, and include all of the most important commodities. Ehrlich would have won posthumously, and by a lot! (Even of the original five, he is four for five, having lost on the least significant of the five: tin.) So, please "Cornucopians," let's not hear any more of the Ehrlich-Simon bet, which proves, in fact, both that man is mortal and must make short-term bets, and, more importantly, that Ehrlich's argument was right (so far).

8 Donella H. Meadows, Dennis L. Meadows, Jørgen Randers, and William W. Behrens, III, The Limits to Growth, Universe Books, New York, 1972.
9 Copper, chromium, nickel, tin, and tungsten.

Appendix 2: The Devil and the Farmer



Source: GMO

Appendix 2: The Devil and the Farmer

Our Midwestern farmer starts with a soil depth of 16 inches*, producing $100 of crops. He has a profit margin of 3% on his crops - the average operating profit margin for U.S. farms is 11% (2010 Family Farm Report, USDA Economic Research Service), but our farmer is completely sustainable and cleaner than clean, incurring no erosion or pollution.

The Devil approaches him and asks if he will allow his soil to deplete at just under 0.16 inches per year - 1% of his soil** - for forty years. In return the Devil will multiply the farmer's profit margin by 5 times, from 3% to 15%. We assume, and the farmer is told by the Devil, that the productivity of his soil and therefore the size of his crop, will fall proportionally to the fourth root of the soil depth (this is approximately in line with empirical studies of soil depth and productivity).

The first time the farmer is approached, taking the Devil's deal will multiply the present value of the next forty years' profits by 4.83 times (at a 6% discount rate). He takes the deal. Forty years later he only has 64% of his soil left…

	First Forty Years			
	Devil's Deal		No Deal	
	Soil Depth	Profits	Soil Depth	Profits
First Year	15.8	$14.96	16.0	$3.00
Tenth Year	14.4	$14.62	16.0	$3.00
Twentieth Year	13.0	$14.23	16.0	$3.00
Thirtieth Year	11.6	$13.83	16.0	$3.00
Fortieth Year	10.2	$13.42	16.0	$3.00
NPV of Profits (6% discount rate)		$217.94		$45.14

The Devil approaches the farmer again after the first forty years. This time signing the deal will multiply the present value of his profits by 4.78 times. He takes the deal. Forty years later he only has 36% of his soil left…

	Second Forty Years			
	Devil's Deal		No Deal	
	Soil Depth	Profits	Soil Depth	Profits
First Year	10.1	$13.37	10.2	$2.68
Tenth Year	9.0	$12.99	10.2	$2.68
Twentieth Year	7.8	$12.55	10.2	$2.68
Thirtieth Year	6.8	$12.09	10.2	$2.68
Fortieth Year	5.8	$11.62	10.2	$2.68
NPV of Profits (6% discount rate)		$193.14		$40.37

The Devil approaches the farmer again. This time signing the deal will multiply the present value of his profits by 4.71 times. He takes the deal. Forty years later he only has 16% of his soil left…

	Third Forty Years			
	Devil's Deal		No Deal	
	Soil Depth	Profits	Soil Depth	Profits
First Year	5.7	$11.57	5.8	$2.32
Tenth Year	4.8	$11.12	5.8	$2.32
Twentieth Year	4.0	$10.61	5.8	$2.32
Thirtieth Year	3.2	$10.06	5.8	$2.32
Fortieth Year	2.6	$9.49	5.8	$2.32
NPV of Profits (6% discount rate)		$164.61		$34.96

The Devil approaches the farmer again. This time signing the deal will multiply the present value of his profits by 4.55 times. He takes the deal. Forty years later he only has 4% of his soil left…

	Fourth Forty Years			
	Devil's Deal		No Deal	
	Soil Depth	Profits	Soil Depth	Profits
First Year	2.5	$9.43	2.6	$1.90
Tenth Year	2.0	$8.87	2.6	$1.90
Twentieth Year	1.4	$8.22	2.6	$1.90
Thirtieth Year	1.0	$7.50	2.6	$1.90
Fortieth Year	0.6	$6.71	2.6	$1.90
NPV of Profits (6% discount rate)		$129.87		$28.55

The Devil approaches the farmer again. This time signing the deal will multiply the present value of his profits by only 3.97 times. He takes the deal. Even this fifth time, starting with only 4% of the soil, he will still make 77% more profits in this period by signing than if he had never signed at all.

	Fifth Forty Years			
	Devil's Deal		No Deal	
	Soil Depth	Profits	Soil Depth	Profits
First Year	0.6	$6.62	0.6	$1.34
Tenth Year	0.4	$5.81	0.6	$1.34
Twentieth Year	0.2	$4.74	0.6	$1.34
Thirtieth Year	0.04	$3.35	0.6	$1.34
Fortieth Year	0.000	$0.00	0.6	$1.34
NPV of Profits (6% discount rate)		$80.07		$20.19

After 200 years and five signings of the Devil's deal, there is no soil left at all. All of the farmer's future profits are zero - and what is more concerning to the rest of us, the farm's future food production is zero.

But the Devil's deal is profitable right up until that point. It is not until year 193 of the Devil's deal that the profits from signing with the Devil all along fall below the profits from never signing with the Devil at all. In fact, if the farmer were made to choose in year 1 between signing with the Devil permanently or never signing at all, his discount rate would need to be **0.17% or lower** for not signing to be the rational choice in NPV terms.

* *This refers to topsoil or "agriculturalist's soil," specifically, the A and B soil horizons.*

** *In fact the Devil's soil depletion will fall over time, from 0.16 inches in the first year to 0.13 inches in the fortieth year. It will continue to fall linearly to 0.08 inches in the one-hundredth year, and 0 inches in the two-hundredth year - because the Devil's deal is that the farmer's soil runs out in the two-hundredth year.*

Source: GMO

Appendix 2: The Devil and the Farmer

The Devil's offer of 5x profits is quite clearly too good for our farmer to pass up. But what if the farmer were much more profitable to start with? What if he had 7.5% profit margins - closer to the U.S. average of 11% - and the Devil could only offer to double his profits to 15%, in exchange for the same soil depletion schedule? Would this still be a good deal for the farmer?

The first time our (more profitable) farmer is approached, taking the Devil's deal will multiply the present value of the next forty years' profits by 1.93 times (at a 6% discount rate). He takes the deal. Forty years later he only has 64% of his soil left…

	First Forty Years			
	Devil's Deal		No Deal	
	Soil Depth	Profits	Soil Depth	Profits
First Year	15.8	$14.96	16.0	$7.50
Tenth Year	14.4	$14.62	16.0	$7.50
Twentieth Year	13.0	$14.23	16.0	$7.50
Thirtieth Year	11.6	$13.83	16.0	$7.50
Fortieth Year	10.2	$13.42	16.0	$7.50
NPV of Profits (6% discount rate)		$217.94		$112.85

The Devil approaches the farmer again after the first forty years. This time signing the deal will multiply the present value of his profits by 1.91 times. He takes the deal. Forty years later he only has 36% of his soil left…

	Second Forty Years			
	Devil's Deal		No Deal	
	Soil Depth	Profits	Soil Depth	Profits
First Year	10.1	$13.37	10.2	$6.71
Tenth Year	9.0	$12.99	10.2	$6.71
Twentieth Year	7.8	$12.55	10.2	$6.71
Thirtieth Year	6.8	$12.09	10.2	$6.71
Fortieth Year	5.8	$11.62	10.2	$6.71
NPV of Profits (6% discount rate)		$193.14		$100.93

The Devil approaches the farmer again. This time signing the deal will multiply the present value of his profits by 1.88 times. He takes the deal. Forty years later he only has 16% of his soil left…

	Third Forty Years			
	Devil's Deal		No Deal	
	Soil Depth	Profits	Soil Depth	Profits
First Year	5.7	$11.57	5.8	$5.81
Tenth Year	4.8	$11.12	5.8	$5.81
Twentieth Year	4.0	$10.61	5.8	$5.81
Thirtieth Year	3.2	$10.06	5.8	$5.81
Fortieth Year	2.6	$9.49	5.8	$5.81
NPV of Profits (6% discount rate)		$164.61		$87.41

The Devil approaches the farmer again. This time signing the deal will multiply the present value of his profits by 1.82 times. He takes the deal. Forty years later he only has 4% of his soil left…

	Fourth Forty Years			
	Devil's Deal		No Deal	
	Soil Depth	Profits	Soil Depth	Profits
First Year	2.5	$9.43	2.6	$4.74
Tenth Year	2.0	$8.87	2.6	$4.74
Twentieth Year	1.4	$8.22	2.6	$4.74
Thirtieth Year	1.0	$7.50	2.6	$4.74
Fortieth Year	0.6	$6.71	2.6	$4.74
NPV of Profits (6% discount rate)		$129.87		$71.37

The Devil approaches the farmer again. This time signing the deal will multiply the present value of his profits by only 1.59 times. He takes the deal. But the soil depletion has taken its toll: he will make only 71% of the profits over this period that he would have made had he never signed with the Devil.

	Fifth Forty Years			
	Devil's Deal		No Deal	
	Soil Depth	Profits	Soil Depth	Profits
First Year	0.6	$6.62	0.6	$3.35
Tenth Year	0.4	$5.81	0.6	$3.35
Twentieth Year	0.2	$4.74	0.6	$3.35
Thirtieth Year	0.04	$3.35	0.6	$3.35
Fortieth Year	0.000	$0.00	0.6	$3.35
NPV of Profits (6% discount rate)		$80.07		$50.47

The deal is still too good to pass up if the Devil only offers to double his profits. Truth is, even doubling the farmer's profits is still a far better deal than the Devil needs to offer. It takes 200 years for the Devil to take all of the farmer's soil - and 200 years is a very long time to discount over.

In fact, if the farmer has a 6% discount rate, the Devil only needs to offer to boost his profits **by 4.3%** - that is, **from $7.50 to $7.82** in the first year - in order for the farmer to rationally take the deal.

Source: GMO