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Save Our Soils

Research needs to step up to the challenge of better managing Earth's soils – for food production and much more, says Steve Banwart.

Many researchers focus on how to intensify agriculture for a growing, hungry world. So far, they have largely dodged the question of how global soils will cope.

Our planet's soils are under threat, as witnessed in the past decade by dust bowl conditions in northwest China, the desertification of grasslands in Inner Mongolia, and massive dust storms across north central Africa. Ambitious plans are in place to help stabilise the soils of the Sub-Sahara with a pan-Africa green belt: a 17 km-wide strip of forested land stretching 7,000 km from the Red Sea to the Atlantic. Compiled rates of erosion from conventional agriculture show that soil losses in some locations can be over 50 tonnes per hectare in a year [1]: up to 100 times faster than the rate of soil formation, and equivalent to losing nearly a half-centimetre-layer of this precious resource.

At the same time, global growth in human population and wealth requires a major intensification of agriculture worldwide to meet an expected 50% increase in demand for food by 2030, and possibly a doubling by 2050 [2]. These numbers do not bode well. Fundamental scientific knowledge needs to get ahead of the curve and develop a predictive framework for soil loss quickly, to systematically evaluate potential solutions and implement the best ones.

There is a way forward. A global network of research field sites called Critical Zone Observatories has been established during the past 4 years. Multidisciplinary teams are focussing on the fundamentals of soil production and degradation, and aiming to create quantitative, predictive models. This programme of research has enormous potential. It can and should be accelerated, with stronger collaboration between national programmes and strong links to policy makers.

Critical Losses

Soil lies at the heart of Earth's 'critical zone': the thin veneer extending from the top of the tree canopy to the bottom of our aquifers. Soil forms as rock breaks up and dissolves, with help from soil organisms, creating particles that bind with decaying biomass and living microbes. Fertile soil is rich in these relatively larger aggregates: at least 60% of fertile soil mass consists of particles in the size range of 0.25-10mm [3]. These aggregates provide a good balance of mineral and organic nutrients, which are processed into forms useful for plants by microbes. The pores within and between soil aggregates retain sufficient moisture for biological growth, facilitate drainage, and allow for an ample supply of oxygen to reach down to plant roots.

The natural capital built up in soil is lost as it is washed from fields by rainfall or snatched away by dust storms during drought. Soil is degraded by pollution, salt concentration from evaporating irrigation water, and compaction by heavy machinery that damages soil pores and aggregates. And it is literally sealed up as cities pave and roof over it: the footprint of

Europe's cities has increased nearly 80% since the 1950's and is set to double this century [4]. In warmer conditions, microbes can degrade organic matter faster, such that CO_2 and other greenhouse gases are released to the atmosphere, the desired soil aggregates are lost, and nutrients are depleted quickly. One study estimates that soils in England and Wales are losing 0.6% carbon each year, probably thanks to climate change [5].

The stakes are high because soil does far more than support farming and forestry: it stores carbon, filters water, transforms nutrients and sustains necessary biodiversity [6]. It is not clear how these essential roles for soil will respond to agricultural intensification and other human-driven changes, how they might be enhanced in tandem with farming, or how this will affect humanity. Critical Zone Observatories (CZOs) are designed to help fill these gaps.

Critical Answers

The US National Science Foundation has invested $30 million in 6 CZOs and 11 affiliated sites. This is primarily a basic science endeavour to understand the details of Critical Zone development and soil processes in diverse environments, from drylands in Arizona to tropical forests in Puerto Rico, and from coastal Delaware to the Rocky Mountains. The European Commission supports an approximately $10 million CZO programme with 10 sites in Europe, the United States and China – focussed precisely on the soils challenge. Four core sites represent key stages of the soil cycle. The Damma Glacier CZO in Switzerland is being used to study initial soil formation, on bedrock exposed as the glacier retreats due to global warming: 150 years of soil formation can be followed there. The Fuchsenbigl CZO in Austria studies the development of soil fertility on a floodplain: sediments deposited along the Danube River since the last glaciation reveal progressive stages of soil formation over thousands of years. The Lysina CZO in the Czech Republic tackles soil recovery in managed forests, in an area where acid rain caused serious damage during the late 20th century. The Koiliaris CZO in Crete, Greece, has mature soils impacted by millennia of agriculture and under imminent threat of desertification due to global warming. Together, these are providing data sets to develop from fundamental scientific principles a predictive model of soil quality, to put monetary value on soil ecosystem services and the environmental costs of changing land management, and to pro-actively design solutions.

There are now over 30 CZOs worldwide [7]. Collectively, they have huge potential to transform soils research. Comparing sites from the Sahara to the Arctic will help, for example, to assess the impact of climate on soil. This is particularly urgent for the Mediterranean basin, where the IPCC predicts a 1-5.5^{o}C warming this century, mostly in summer, a 30-45% decrease in precipitation and 6-36% decrease in runoff by 2070 [8]. A quantitative model of soil quality could be used to assess the costs and benefits of different mitigation strategies, from enforcing less grazing to revitalising terracing, encouraging composting, or switching to a different mix of crops.

Two key ingredients are still missing from this effort. One: better international integration of research methodology to unite the CZO programmes. Work on this is just beginning. In September 2008, The Koiliaris CZO hosted teams from Europe, China and United States for the first joint training event; in 2010, Penn State University ran an international Critical Zone field course; and the University of Colorado hosts an international symposium for young Critical Zone scientists this June. The CZO teams are developing methods to create cohesive data sets and models that work across all sites; to study a greater geographical range of Critical Zone environments, and to maximise the new knowledge being created.

Two: there needs to be a stronger effort to integrate research with government and commercial stakeholders. The directed research that is driven by EU policy and the basic research of the NSF programme are a powerful combination. Including commercial partners in new research planning will further establish the most direct routes from new knowledge to practical solutions.

The challenge is clear. We need rigorous forecasting methods to quantify and best utilise soil's natural capital, to assess options to maintain or extend it, and determine how existing declines can be reversed. And we need it well within a decade.

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