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REVIEW ARTICLE

The future of weed science

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ABSTRACT

Agricultural scientists, farmers, ranchers, and the agriculture industry remain confident of their basic faith in the possibility of continued increasing production through intelligent use of ever more efficient agricultural technology and research. Increasing production has been and remains the accepted way to achieve the moral obligation of feeding a growing population. Therefore, the weed management scenario has become one of the important factors. This brief essay questions if agriculture's moral justification will hold as widespread, rational scientific and moral arguments about human and environmental harm, public fear of technology, and concern about food quality dominate.

Keywords: Ecology, Education, Ethics, Evidence, Faculty, Facts, Future, Goals, Herbicides, History, Island empire, Management, Opposition, Paradigm, Pesticides, Production, Public health, Questions, Sustainability, Teaching, Technology, Risk, Values, Weed.

INTRODUCTION

We can, of course, be deceived in many ways. We can be deceived by believing what is not true; but we certainly are also deceived by not believing what is true.

Kierkegaard - Works of Love.

I have chosen to begin with a topic clearly related to climate change and weed management that will affect weed science's future and global food security. My topic - agricultural ethics1 is a philosophical reflection on the future of weed science and agriculture, It is a challenge to you. Comments on weed science research and technology will follow (Section III).

AGRICULTURAL ETHICS

Universities routinely include ethical study in the curriculum for medicine, law, business, and the environment. Agriculture, the essential human activity and the most widespread human interaction with the environment does not. The agricultural science curriculum lacks consideration and study of the effects of agriculture on society and the environment. Ethics has not been institutionalized in Colleges of Agriculture, agricultural professional organizations, or the agribusiness industry. That is not to say there are no professional ethical standards.

Many assume agriculture has an adequate ethical foundation. The assumption is not questioned. There has been too little investigation and too little critical thinking about the lack of and need for an ethical foundation.

Agriculture has scientific challenges: achieving sustainability, maintaining production, pesticide and antibiotic resistance, invasive species, loss of biodiversity, biotech/GMOs, and pollution. Those involved in agriculture believe development and use of more energy dependent technology is always good and more will be better. It will address the need for production, address the problems caused by the unintended consequences of present technology, and alleviate public concern.

I do not mean to imply that we should abandon science and technology. We humans, the earth's dominant species, are not just figures in the landscape — we are shapers of the landscape (Bronowski 1973, p.19). Having achieved this power, we should think carefully about whether what we do is desirable. Although all involved in agriculture know what they are doing they should think about what they may be undoing.

The moral imperative is to produce food and fiber to benefit all humanity. Production is what must be sustained. Agricultures producers, suppliers, and researchers regardless of their employer should ask if

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production is a sufficient criterion for judging the consequences of all agricultural activities. Does increasing production justify everything agriculture does? Does it achieve sustainable production practices? Does the quest to increase production solve or even address agriculture's moral dilemmas?

Agricultural scientists have assumed that as long as their research and the resultant technology increased food production and availability, they and the end users were somehow exempt from negotiating the moral bargain that is the foundation of the modern democratic state (Thompson 1989). It is unquestionably a moral good to feed people. Therefore, it is assumed, anyone who questions agriculture's morality or the results of its technology simply doesn't understand the importance of what is done and how it is done. It is assumed that agricultural practitioners are technically capable and that the good results of their technology will make them morally astute.

When those involved in agriculture claim credit for improving production and keeping food cost low, they must also accept society's right to hold them responsible for problems often regarded as externalities. They need to ask and be prepared to respond to what has not been asked often enough. What could go wrong? What has gone wrong? What are the appropriate responses?

We live in a post–industrial, information age society. No one will ever live in a post-agricultural society. Continuing to justify all agricultural activities and technology by the necessity of achieving the moral obligation and production challenge of feeding a growing world population has not been and will not be a sufficient defense for agriculture's negative environmental and human effects. We are disturbing and changing the climate and our planet's ecosystems at a pace and scope never seen in human history (Friedman 2016).

What is the problem? Feeding the 11 billion expected to be on the planet at the end of this century is undeniably a good thing. Is it a production problem? Of course it is. But enough food is produced now to feed the global population3. Nevertheless about 810+ million people still go hungry every day. After steadily declining for a decade, world hunger is on the rise, affecting 1 of 9 of the world's people. From 2019 to 2020, the number of undernourished people grew by 150 million, a crisis driven largely by conflict, climate change, and the COVID-19 pandemic. In spite of the abundance of food, people are hungry because of inadequate food distribution, inadequate infrastructure that delays or prevents food distribution, food storage waste, waste by consumers, government policies, and poverty.

More production will not solve the hunger problem (Sen 1999).

It is obvious citizens of democratic societies are becoming increasingly reluctant to entrust their water, their diets, and their natural resources blindly into the hands of farmers, agribusiness firms, and agricultural scientists. Ethicists and agricultural practitioners must initiate and participate in a dialog that leads to social consensus about the effects of agriculture's technology, its risks, and reasonable solutions. In the past most risk was borne by users of the technology. Now there is widespread concern the risks and short- and long-term consequences of agricultural technology are borne by others. Agriculturalists must begin to contribute the time and resources needed to listen and explain their positions and understand those of their fellow citizens. All involved in agriculture and those who enjoy abundant societies must recognize they are dealing with how we ought to live.

Agriculture practice, research, and teaching involves scientific and ethical values. Feeding the growing world population is clearly a very good thing, but it does not absolve the agricultural community from critical, ethical examination of the totality of agriculture's effects.

People throughout the world have rational concerns about the ethical dimensions of agriculture and our food system that go beyond the central need to feed humanity. Each of agriculture's multiple responsibilities includes an ethical dimension (achieving sustainability, resolving pollution of water, soil, and humans, harming other species and cruelty to animals, stopping habitat destruction. Assuring availability of surface and ground water, stopping exploitation and inhumane treatment of farm labor, stopping loss of small farms and rural communities, considering the power of corporate farming and its lack of transparency, stopping harmful treatment of animals, addressing public concern about botechnology/GMOs, Stopping loss of crop genetic diversity, and addressing public concern about the nutritional value of foods provided by the food system.

These are not just scientific problems. We should not expect scientists alone to solve them. Leaders of the agricultural enterprise should work together with others to identify, discuss, and address them. Collective action is required to achieve morally

good goals. Agriculture will gain little if it wins the production battle and loses the moral battle.

Agricultural education has given too much emphasis to what to think rather than how to think. Universities have traditionally been places where different opinions were welcomed and encouraged. The present trend toward specifying what controversial topics may or may not be welcome is disturbing. It stands in sharp contrast to the role of teaching - to lead out - to educate. Encouraging students and the general public to be aware of and discuss difficult controversial issues is an important role of education and those who teach.

There are 113 universities in the world with agricultural faculties. Forty US universities and only 7% of all other universities that offer agriculture education have departments of weed science (Ahmad *et al*. 2023). Only six US universities have a course on agricultural ethics. The worldwide agricultural curriculum lacks courses that focus on general ethical principles and their application to agricultural issues.

It is my view the lack of university courses on agricultural ethics in the United States is because the faculty who teach, plan the curriculum, and advise undergraduate and graduate students do not regard studying the ethical values of agriculture as important preparation for agricultural professionals. When I was a student, I was never advised to enroll in a class in philosophy, and I assumed that my professors and their mentors were not advised. Present faculty are not interested in or do not care to cooperate with a colleague in the Department of philosophy to create a class on agricultural ethics and encourage students to enroll.

Such classes will be a recognition of the need to acknowledge and discuss agriculture's ethical dimensions. Agriculture has (Zimdahl and Holtzer 2016) problems which have focused attention on production and profit while education and practice have ignored agriculture's human and ethical dilemmas (Damasio 1994).

Professors, Department heads, and Deans of Colleges of Agriculture who have not chosen to address agriculture's ethical dilemmas are contributing to the problems. There is a clash between the environmental and human harm of modern, agricultural production and the values held by the general society and those who practice agriculture. Ignoring value conflicts and societal concerns will lead to a loss of public support and trust in agriculture.

Our technology may outweigh our character. We hold at the level of our training - our education. We risk becoming moral people in an immoral profession (Niebhur 1932). "He who knows only his side of the case knows little of that"Mill 1859). We must begin to interact and listen to people who don't share our beliefs and who confront us with evidence and counter arguments (Haidt 2022).

What we resist pursues us. What we accept transforms us. We are a mass audience consuming the same content while looking in a mirror reflecting the view we have (Haidt 2022). My experience has shown students may be more willing than the faculty to question and explore outside the agricultural curriculum

When the morally good goal of feeding a growing world population bumps up against the morally good goal of protecting the environment one is confronted with value questions that science is not designed to and cannot answer. When the environment's natural objects are valued only in terms of their worth to humans they can be and are legally destroyed or modified.

I offer a few examples of what we have and are doing. We cut down original forests, till the prairies, irrigate deserts, dam and pollute streams, overgraze hillsides, flood the valleys, and prevent forest fires. We have changed the climate and acidified the oceans. Little, if any, attention is paid to the inevitable environmental consequences: ocean hypoxic areas, soil erosion, melting ice, species extinction, invasive species. Our predatory self-interest dominates our environmental concern. Kolbert (2022) correctly noted - It seems normal to send in the bulldozers, chainsaws, and backhoes to cut down the trees, fill the wetlands, and "develop" the land.

Until something or someone receives a right granted by law or public pressure we often see the environment as something for our use. The objection that streams and forests cannot speak has been addressed. Neither corporations, States, estates, infants, incompetents, municipalities nor universities can speak. These entities are amply represented — some might say over represented — in the courts. We make decisions on the behalf of and in the purported interest of others every day. The other creatures (eg. soil microroganisms, pollinating insects) whose wants are far less verifiable may be more important. They are more metaphysical (the fundamental nature of reality) in conception than the wants of rivers, rocks, (Nash 1977), Trees (Stone 1972) and the human benefits from and obligation to them.

Is it possible for human intelligence to increase the range of benevolent impulses and encourage us to consider the needs and rights of other humans in addition to the things to which we are bound by organic and physical relationships? Can we transcend our own interest to grant rights to the interests of our fellow humans and the creatures in the environment? If agriculture's practitioners continue to ignore agriculture's moral dilemmas because we must produce they may lose the right to determine agriculture's future and jeopardize our chances of surviving on this planet (Berry 1977). If we fail to institutionalize study of the ethics of agriculture we will not learn how to ask and discuss moral questions. We should not continue to defend only the interests of agriculture when there are obviously unjust effects on the interests of the planet and our social communites. Human ingenuity has increased the treasures nature provides for the satisfaction of human needs; it will never be sufficient to satisfy all human wants.

Prediction of the future for weed science and agriculture is always tempting, often successful, and usually hazardous. If all parts of the agricultural enterprise including professors, farmer/rancher producers, agribusiness firms, and food processors, and sellers do not begin to recognize and address agriculture's ethical dilemmas three unwelcome outcomes may follow.

First- Agriculture practitioners may find their arguments and justification for their technology and production practices ignored.

Second- Public unease and dissatisfaction with known and perceived effects of agricultural technology (*e.g.* pesticides, cruelty to animals, farm labor, and food quality) will result in increasing societal unrest and pressure for political action. Decisions on how agriculture can be practiced and how land is to be treated will be made by society and government.

Third- The increasing concentration of food production in the hands of agribusiness companies will continue. Small farms, farmers, and rural communities will continue to gradually disappear.

Agriculture is a capital-intensive, high-tech business. Rather than wait to see if appropriate levels of sustainability and resilience can be achieved by the present capital, chemical, and energy intensive system, agricultural people could begin to learn how to impose ethical standards on themselves. Because agriculture is a diverse widespread enterprise reaching agreement will be difficult, but not impossible. Recognizing the possible undesirable outcomes and choosing to act wisely will help maintain the essential industry. I challenge you to consider some hard questions that will affect your future: What does it mean to live well? What matters?

What needs and values do you live by. What needs and values ought you live by.

THE FUTURE OF WEED SCIENCE RESEARCH AND TECHNOLOGY

Prophesy is a difficult thing, especially of the future. I hope my comments make you think. Weed science, although young among the agricultural sciences, has an enviable, rich, productive history and will continue to contribute to agriculture, other disciplines, and food production. Weed control was recognition of necessity by farmers who had been controlling weeds long before herbicides were invented. Herbicides changed the way control was done, but not its fundamental purpose —to improve yield of desirable species. The chemical energy of herbicides replaced human, animal, and mechanical energy. No other method of weed control was as efficient at reducing the need for labor or as selective. People with hoes could distinguish weeds from crops and weed selectively. Mechanical and cultural methods, while effective, were not selective enough. Herbicides enabled prevention, reduced weed populations, and selectively removed weeds from crops. Weed control in the world's developed countries now depends on herbicides. This situation will prevail well into the 21st century.

A. Problems

There are six important problems that have and may continue to hinder progress.

1. Although weeds have been and will continue to be components of agriculture and the environment, they lack the attention, appeal, and urgency of sudden infestations of other pests.
2. Weed science lacks foundational hypotheses "linked to established bodies of ecological and evolutionary theory to provide deeper theoretical justification, a broader vision, and increased collaboration across diverse disciplines (Ward *et al*. 2014). Environmental and production demands will require significant adjustments in weed management and agricultural practice.
3. There is a lack of people and research funds (Davis *et al*. 2009). Research on weed biology, ecology, seed dormancy, and other problems leading to basic understanding rather than immediate control is done by too few scientists.

Publicly funded interdisciplinary agricultural research has lacked adequate funding and, it seems, may remain so (Davis *et al.*).

4. Underlying all agricultural issues there is always an unexamined ethical position (Zimdahl 2022). Thompson (1995) pointed out there is only one imperative: to produce as much as possible, regardless of the environmental/ecological costs and perhaps even if it is not profitable. Agricultural people cannot escape responsibility for societal views of its effect on the environment, other species, and themselves. Agriculture's views on ethical issues have not been and should be examined.
5. All in agriculture know farming is crucial to all economies (Economist 2022) and important to the welfare of all. The public in most societies is certain food is important but is abysmally unaware of the complex processes and people who provide their food.
6. Climate change and lack of appropriate weed control practices will affect farmer's ability to produce. Modern agricultural technology developed country farmers rely on is beyond the reach of poor farmers in the developing world. More than 90% of farmland in Africa has no irrigation, 1/3 of the world's people, and 60% of Africans do not receive warning of impending natural disasters or routine weather forecasts. Agriculture's admirable goal of feeding an expanding world population in warmer, drier places will benefit from expanding its horizons to developed country farmers.

A few conflicting claims (cited herein) illustrate future challenges.

- Moss (2008) charged the overall direction of weed research was wrong. There was too much emphasis on scientific effect at the expense of practical application. Moss argued weed science was weed technology. He suggested his colleagues lacked an awareness of the complexities and resources needed to translate research results into actions for farmers.
- Ward *et al.* (2014) claimed two broad aims have been driving weed science research: improved weed management and improved understanding of weed biology and ecology. Research has developed a high level of repetitiveness, a preponderance of purely descriptive studies, and has failed to clearly articulate novel hypotheses linked to established bodies of ecological and evolutionary theory. Although Ward *et al.* (20214) noted studies of weed management remain important they urged weed scientists to recognize the benefits of deeper theoretical justification, a broader vision, and increased collaboration across diverse disciplines (especially ecology).
- Swanton (2022) accused weed science of being primarily reactive. Scientists responded to current need and worked to solve on-farm problems. He recommended the discipline make long-term thinking automatic and common instead of rare. Long-term thinking is required because weed science, a sub-discipline of agriculture, must begin to answer complex questions regarding cropping systems and environmental challenges.
- The Editor-in-Chief of Weed Research (Marshall 2019) introduced "the post-herbicide era of weed science". He argued this was "increasingly prescient as herbicides continue to face the ever-increasing legislative restrictions and the challenge of evolved resistance. They are key influences of the practice of intensive agriculture whose success is intimately linked to the heart of the planetary crises: climate change, global warming loss of biodiversity, environmental harm, etc.
- Buhler (2017) argued weed scientists must develop integrated cropping systems and weed control strategies in a comprehensive environmental and economically viable system. This approach would "help reduce economic effects and improve weed control practices." Herbicides will continue to be an essential part of integrated cropping systems.
- Westwood *et al.* (2018) claimed weed science was at a "critical juncture" because decades of chemical control have dramatically increased herbicide resistant weed populations. The problems were critical because there were few new herbicides, new modes of action, and no economically acceptable alternative to herbicides in large acreage crops. They suggested new modes of action could be discovered using genetic engineering, computing power, automation, employment of artificial intelligence and machine vision to improve weed management.
- Gould (2002) portrayed the situation by contrasting "immediate and practical" with "distant and deep" issues. Immediate and practical issues are about potent and

unanticipated effects (*e.g.* herbicide resistance). Distant and deep issues include legislative, ethical, aesthetic and practical consequences of altering agriculture's fundamental geometry and permitting scientist's in the developed world to change the way agriculture is and ought to be practiced. He advocated proper development and use while giving adequate, consideration to human and environment health, and sustainability.

This paper deals with thoughts about future weed science research, but not in terms of what will be accomplished. It is conjecture, not prophecy. It might be best conceived as a proposal of what ought to be done. It may not be what will be done because research does not always follow a straight path and other developments may change what is desirable and possible. For example, environmental legislation mandating reduced herbicide use could rapidly change the way agriculture is practiced. A description of research needs is a safer prophetic stance. It describes what could be done rather than describing what the situation will be several years hence. This approach, of course, reduces the possibility the prophet may be wrong.

B. Research needs

Dependence on herbicides for weed control is equivalent to treating the symptoms of a disease without actually curing the disease. Agriculture would be far better served if weed scientists learned how to control weed seed dormancy and seed germination so weeds could be prevented, rather than controlled after they appear. The emphasis should be on the major goals put forth by Ward *et al.* (2014).

1. Discussion and debate of appropriate goals and the pathways necessary to achieve the goals.
2. Rediscovery of the ability to pose critical research questions rooted in and designed to advance the theoretical underpinnings of weed science.

Weed science began when 2,4-D made control possible without studying the weeds. Those who controlled had to know what weeds were to be controlled and where they were growing. That is, control was not blind. There are objects to be controlled and they are known, but, with herbicides, it has not been necessary to know much more.

In general, herbicide development has neither exploited weak points in a plant's life cycle nor used specific physiological knowledge for control purposes. The safest approach has been to aim for complete control of weeds in a crop. As knowledge grows, scientists find some plants may be beneficial and should not be controlled (Chandrasena 2023). Wyse (1992) recommended study of regulation of seed and bud dormancy of perennial weeds and development and life of reproductive propagules. Population genetics and modeling of crop-weed systems will contribute to improved weed management.

C. Weed ecology

Important insights on the future role of weed ecology are found in two papers - Neve *et al.* 2018 (35 authors) and MacLaren *et al.* 2020 (6 authors). Both support the increasingly dominant claim - the present weed management system is unsustainable because of its negative effects and dependence on chemical, capital, and petroleum energy. Both advocate combining multiple known weed management techniques in a new integrated weed management system. Creation of an integrated system based on agro-ecological approaches will require multi-disciplinary participation (Jordan *et al.* 2016). MacLaren *et al.* (2020) argue "new herbicides, gene editing, and seed destructors do not address needed systemic challenges and are unlikely to provide sustainable solutions." Neve *et al.* (2018) advocate better understanding of weed evolution, climate change, weed invasiveness" and, perhaps the greatest challenge, "disciplinary challenges for weed science". They advocate "integration of agro-ecological weed management with socio-economic and technological approaches".

The system that helped create these problems accepts credit but resists accepting blame for negative effects, therein is part of the tragedy. It is an example of the agricultural mind set and justifies Mayer and Mayer's (1974) conclusion - the system is unsustainable. Their second claim - integration and isolation of the system have led to The Island Empire. Agriculture is a vast, wealthy, powerful intellectual and institutional island. The Land-Grant system created Colleges of agriculture and allowed agriculture's isolation within the university and from mainstream American life. Mayer and Mayer accuse agricultural colleges of being separated from the university, mainstream of scientific thought, and rational discussions about social policy. Agriculture does not ask for and only reluctantly receives outside criticism. Those who practice agriculture must move off their island.

Much of the basic information required to develop computer-based models of weed-crop systems and available control techniques has come

and will continue to be derived from weed biology and ecology research. What plants compete for and when competition is most severe between crops and weeds is known in sufficient detail to be useful in development of weed-management systems. The still used (Dawson 1965) period threshold concept of weed competition affirms it is nearly always time dependent. Weeds at crop emergence are less detrimental than those emerging later. This principle led to timely use of herbicides and other techniques for weed management. Some crop cultivars are more competitive and this needs to be considered in developing weed-management systems. It is a basis for cooperative work with plant breeders.

Weed populations change with time, and reasons are beginning to be understood. A major challenge presently dominating weed research is the appearance of herbicide resistance often after only a few years use in one field. Research is coupled with development of techniques to combat it. When resistance occurs it has not led to totally unmanageable weed populations because other weed-control techniques (*e.g.*, cultivation, crop rotation) and other herbicides are available. Understanding why populations change and management of population shifts is important to development of successful, sustainable weed management. However, as Harker *et al*. (2012) note, the best way to reduce selection pressure for herbicide resistance is to reduce herbicide use, but dominant weed-management programs advocate herbicide use.

Some of the most difficult weeds in most crops today were not important 10 or 20 years ago. This is evidence weed scientists have developed solutions to some weed problems. It is also true that many common weeds (*e.g.*, cheatgrass, field bindweed. johnsongrass, lambsquarters, nutsedge, pigweeds, Canada thistle) have been targets of control programs for years. Thus, we have simultaneous evidence of success and continuing problems. It is also evidence that nature abhors empty niches. When successful control efforts have reduced the population of a species they inevitably leave space unoccupied and resources unused. Other species move into empty niches created by successful weed control.

Solutions to this dilemma take two forms. The first is to reduce the attractiveness of the niche. Farmers typically over provide for crops. Fertilizer placement and precise rate recommendations have reduced surplus nutrients, but nitrogen runoff due to excessive application is a significant problem with notable externalities. Whole fields are irrigated and light cannot be controlled. If water could be placed (*e.g.*, drip irrigation) as precisely as fertilizer and only as much was provided, the attractiveness of the niche and the success of potential invaders could be reduced = preventive weed management.

The second approach has an element of prevention. Some of the important problem weeds of the next decade are already in fields or lurking on the edges. If they were identified and their weedy potential determined, weed scientists, cooperating with ecologists (see MacLaren *et al*. 2020), could try to predict those most likely to be successful invaders. They could be controlled or managed before invasion. Invasive plant management is now a major area of weed science research as indicated by the 2008 launch of the journal Invasive Plant Science and Management.

Basic biological-ecological knowledge is essential to either approach. Without it weed scientists may be doomed to endure the Red Queen effect (a character in Lewis Carroll's classic book - Through the Looking Glass - 1871). The Red Queen tells Alice, "In this place, it takes all the running you can do to keep in the same place." In trying, and often succeeding, to eliminate weeds from fields, weed scientists have created, in a sense, better, more ecologically successful weeds while accepting herbicide's negative environmental effects.

A difficult and central issue for weed science is understanding the nature of weeds: What makes a weed a weed? How can weeds consistently come out ahead when matched up against the finest commercial varieties? Weeds out-compete crop plants and reduce yields when left uncontrolled. Weeds are not conscious, but they seem to be clever. The nature of the competitive ability weeds possess seems an interesting target for research and an appropriate target for analysis through generation of mutants.

Goethe's "The Sorcerer's Apprentice" and" Mary Shelley's "Frankenstein," and, more recently, Michael Crichton's "Jurassic Park" reinforce the often-inchoate fear of intelligent, rational concern about a powerful form of life manufactured with good intentions, but excessive hubris, which might one day slip out of control (Specter 2016). The 1950s gave us catchy phrases that still resonate—Better Living Through Chemistry and Atoms For Peace. We don't hear similar things now. Chernobyl/Fukushima nuclear reactors, agent orange, space shuttle crashes, thalidomide, ozone destruction, pesticides in food, and climate change dominate the public's thoughts. Scientists clearly solve problems, but in the public's view, untoward problems occur. These well-known

problems combined with human drug disasters have made people suspicious of the efficacy and trustworthiness of science and scientists (Lemonick 2006). It is in this context public doubts about genetic modification of anything are raised and must be addressed. Weed scientists and others involved with GM technology often think they could educate/tell people about what they do (William *et al*. 2001). Education is important but careful listening followed by a conversation among equals may be better, especially in a time when science has made mistakes and is regarded with well-founded suspicion. Weed scientists should not regard themselves as the only acceptable arbiters of how developments in their science should be created and used. Because of public perceptions of greed, a bit of arrogance on the part of developers, and misunderstanding of science people view genetic modification as a hazard not a salvation and reject it (Specter 2016).

D. Education

A review of some published articles on the future of weed science reveals few comments on the role of education. Research and appeals for more funding (Davis *et al*. 2009) dominate. There is at least one undergraduate weed science class at all US Land Grant universities and several others required of undergraduate and graduate students. The absence of discussion of what students ought to know among those who teach is disturbing. Surely the education of the next generation of weed scientists with "innovative and diverse teaching practices" advocated by Chauhan *et al*. (2017) are as important to the collective future of weed science as biotechnology, invasive species, and new herbicides. If it is, why isn't education closer to the top of the future agenda? We must integrate weed management and education.

IV, Other challenges

A. Scientific

Several other research areas should be considered when planning weed science's future. They include:

- The value, advantages, and disadvantages of monoculture agriculture.
- The role of companion cropping and regular inclusion of cover crops in weed management? Can weeds be cover crops? (See Young 2020)
- The long-term effects of soil erosion after regular plowing and cultivation? One effect is all too apparent in the brown color of rivers (Logan 1995, Montgomery 2007).
- The future and influence of perennial crops.

Weed scientists were not too concerned with long-term effects when the science was developing. Weeds decreased crop yield — a detrimental long-term effect. The vision didn't extend much farther because solving the weed problem was a sufficient challenge. Any technology, used for enough time, has demonstrable environmental and social effects. A longer-term view will help reveal these effects and compel their consideration before widespread use is achieved.

- Weed scientists must begin to work more closely with economists who ask, what does it cost and what is it worth? What is it worth to do the work to develop a more competitive cultivar, deplete the soil seed bank and achieve assurance of 80% or 100% weed control? What will it be worth to be able to predict weed problems? No one knows, but the answers are important to IWM systems.
- Will nanotechnology affect weed science? Nano integrates biological material with synthetic materials to build new molecular structures. Synthetic biology goes beyond moving existing genes to creating new ones programmed to perform specific tasks. It operates at the nano scale (10"9m) of living and nonliving parts. It has enormous potential for good and harm (Shand and Wetter 2006).

Weed scientists are aware of scientific research opportunities and challenges. There are equally important, though less discussed, social and moral challenges. The primary goal of agricultural scientists has been to develop technologies to achieve maximum yield of a few crops in developed countries. It is a good goal, but one must ask if it is the right goal.

- Is it more important than enabling the poor of the world to feed themselves?
- Can discovering new technologies to maximize yields lead to a sustainable agricultural system to feed 9 billion people?
- Is maintaining rural communities a proper goal for agricultural science?
- Should achieving maximum yield and profit always take precedence over preserving the environment? Should agricultural sustainability to increase crop yields simultaneously decrease environmental effect

Achieving a sustainable agriculture is a goal all agricultural scientists share. In spite of its nearly

universal adulation there is little agreement on its nature, what is to be sustained, or on how it is to be accomplished. Production is and always will be important, but it is not possible to create a sustainable agriculture without a sustainable culture. It is impossible to have a serious, comprehensive discussion of sustainable agriculture without including community and culture (Holthaus 2009). Within the agricultural community achieving sustainability is viewed as mainly or wholly technical in nature. It requires different farming methods and adoption of alternative technologies (Morgan and Peters 2006). This ignores the moral, educational, and political tasks and requires a commitment to "philosophical principles that depart from the utilitarian premises of industrial agriculture. It requires new thinking and a change in attitude toward the earth. It requires ceasing attempts to achieve dominion over the earth and achieve humility and reverence before the world (Berry 2002). The dominant agricultural view supports crop intensification as the best route to feed 9 billion people and protect the environment.

Finally, a caution. Weed scientists have an unexamined moral confidence or certainty about the correctness of what they do. The basis of the moral confidence is not obvious to those who have it or to the public. It is potentially harmful. It is necessary to analyze what it is about their science and their society that inhibits or limits their science. All should strive to nourish and strengthen the beneficial aspects and change those that are not. To do this agricultural people must be confident to study themselves, their science, its institutions, and be dedicated to the task of modifying the goals of both (Zimdahl 2022).

V. Agriculture's human dimension

Doohan *et al*. (2010) claim "the human dimension of weed management is most evident when farmers make decisions contrary to science-based recommendations." Agricultural scientists and administrators may be aware their recommendations are often ignored but usually do not ask why because such questions are beyond their area of expertise. Scientists do science leading to science-based recommendations. Reasons for ignoring could be: economic (too expensive), stubbornness, lack of trust, and different perceptions of risk and benefit. Doohan *et al*. argue that farmers exhibit an inverse relationship between perceived risk and benefit. If any technology is regarded as beneficial it is automatically perceived as low risk, which, of course, is not true. Ignoring farmer's reasons is perilous for agriculture's future.

Agricultural scientists have contributed to increasing crop production over several decades. Pesticides have been the primary control technique (Fernandez-Cornejo *et al*. 2014). Because of their efficacy and ease of use there has been over-reliance on them at the expense of other control methods (Blackshaw *et al*. 2008). If the only or primary goal of weed science is to increase production the quest for better herbicides must continue. If the goal is sustainable weed management in a sustainable environment and society other control techniques must be investigated and integrated. Research on non-herbicide weed management must show low or no risk of crop failure and reduced profit. The goal should be development of successful weed-management systems with minimal or no effect on the flora and fauna of soil, water, or air and no adverse effects on people or other creatures.

Scientists and others engaged in agriculture are not, by nature or choice politicians. Failure or inability to consider we live in a political world and are affected by it is a prescription for disappointment or disaster. Political considerations affect our daily life. A major political accomplishment is cheap food, especially in urban areas. It affects the way we practice agriculture and manage weeds. If the government removed itself from agricultural policy making and markets cheap food might disappear.

Given agricultural and environmental history, concern about environmental pollution from agriculture is a fairly recent political development. It wasn't too long ago that pesticide use in agriculture meant prosperity and progress rather than human harm, environmental pollution, and lack of corporate responsibility. For example, a study commissioned by the American Farm Bureau (King 1991) showed 15% of the American public was in favor of abolishing pesticide use in agriculture. Of those surveyed 66% thought pesticide use should be limited in the future and 38% thought farmers were using more pesticides than they had in the past. Such information and concern has political meaning and consequences. About 70% of US agricultural produce harbors some trace of pesticides (Gross 2019). Such challenges are often dismissed by the agricultural community because they are regarded as biased, irrelevant and lack supporting scientific evidence. The findings are ignored or dismissed by those who willfully ignore the effects of criticism on political action (Roberts 2024). Political acts change things and agriculture has to recognize and work in a political milieu or suffer the consequences of regulation by those who do.

VI. Conclusion

The American author Wendell Berry (1981) has written about problems facing American agriculture. He advocates solving for pattern. “To the problems of farming, then, as to other problems of our time, there appear to be three kinds of solutions.” The first solution causes a ramifying series of new problems. This kind of solution shifts the burden away from those who created the problem. The second solution worsens the problem it is intended to solve. These quick-fix solutions ask what herbicide will kill the weed and lead to the need for more quick-fix solutions. The third, most desirable, solution creates a ramifying series of solutions which make, and keep, things whole. For Berry (1981) a good solution is one that acts constructively on the larger pattern of which it is a part. It is not destructive of the immediate pattern or the whole. Good solutions solve for the whole system, not for a single goal or purpose.

Those who create the next generation of integrated, sustainable agricultural production systems for simple and complex problems should remember Berry’s admonition. One must know the whole system and devise solutions that create solutions to maintain the pattern and improve the system. Agriculture’s inevitable problems demand the entire system not just the current problem must be managed.

Contributing to the elimination of hunger in the world is a proper goal for weed science. Two goals of the Millennium goals of the UN (Sachs 2005, pp. 211-212) are relevant. Eradicating extreme poverty and reducing hunger by half and ensuring environmental sustainability.

Although progress has been made, neither goal has been achieved. Berry (1981 p. 98) writes eloquently about a vision of the future shared by those who want to create alternative futures including alternative, improved, sustainable agricultural systems. His words are a good place to end thoughts about the future. Readers may determine if I have reached beyond my knowledge and ability.

We have lived by the assumption that what was good for us would be good for the world. We have been wrong. We must change our lives, so that it will be possible to live by the contrary assumption that what is good for the world will be good for us. And that requires that we make the effort to know the world and to learn what is good for it. We must learn to cooperate in its processes, and to yield to its limits.

But even more important, we must learn to acknowledge that the creation is full of mystery; we will never clearly understand it. We must abandon arrogance and stand in awe. We must recover the sense of the majesty of the creation, and the ability to be worshipful in its presence. For it is only on the condition of humility and reverence before the world that our species will be able to remain in it.

Berry’s challenge is clear - Change requires more than the contemplation of fixed verities. It must move beyond reproducing the qualities of the science to which we have devoted our careers.

REFERENCES

Ahmad T, Jabran K, Chema ZA, Bajwa AA and Farooq M. 2023. A global perspective of education in weed science. *Weed Science* **71**(6): 536-548. DOI: https://doi.org/10.1017/wsc.2023.49

Berry W. 2002. *The Art of the Commonplace. Shoemaker and Hoard*. Washington, DC, p. 330.

Berry W. 1981. Solving for pattern. pp. 134–145. In: *The gift of good land*. North Point Press, San Francisco, CA.

Berry W. 1977. *The Unsettling of America: Culture and Agriculture*. Avon books, NY. 228 p.

Blackshaw RE, Harker KN, O’Donovan JT, Beckie HJ and Smith *EG*. 2008. Ongoing development of integrated weed management systems on the Canadian Praires. *Weed Science*. **56**: 146–150.

Bronowski J. 1973. *The ascent of man. Little*. Brown and Comapny. Boston, MA. 448 p.

Buhler DD. 2017. 50th anniversary - Challenges and opportunities for integrated weed management. *Weed scienc*e **50**(3): 273–280

Chandrasena NR. 2023. *The virtuous weed: weedy by name only not weedy by nature*. Vivid publishing. Freemantle, Western Australia. 474 p.

Chauhan BS, Matloob A, Mahajan G, Aslam F, Florentine S K, and Jha P. 2017. Emerging challenges and opportunities for education and research in weed science. *Frontiers In plant science* **8**: 1537.

Damasio. A. 1999. *The feeling of what happens: body and emotion in making of consciousness*. A Harvest book. Harcourt Inc. New York. 285 p.

Davis AS, Hall JC, Jasieniuk M, Locke MA, Luschei EC, Mortenson DA, Riechers D.E. 2009. Weed science research and funding: A call to action. *Weed science* **57**: 442–451.

Dawson JH., 1965. Competition between irrigated sugar beets and annual weeds. *Weeds* **13**: 245–249.

Doohan D, Wilson R, Canales E, Parker J. 2010. Investigating the human dimension of weed management: new tools of the trade. *Weed Science **58***: 503–510.

Economist. 2022. Room at the bottom – pp. 8-9. In: *Special report climate adaptions*. November 5, 2022.

Fernandez-Conejo, Nehring JR, Osteen C, Wincester S, Martin A, and Vialou A. 2014. USDA.-Economic research service. Economic Information Bulletin No. 124. 86p. www.ers.usda.gov.

Friedman TL. 2016. *Thank You For Being Late - An optimist's guide to thriving in the age of accelerations.* Farrar, Straus and Giroux. New York. 486 p.

Gould SJ. 2002. On the origin of specious critics. *Discover*. January. pp 34-42.

Gross L. 2019. More than 90% of Americans have pesticides or their byproducts in their bodies. The real risk from chemicals in our food for farmers and children, in p particular are being ignored. The nation. Https://www.thenation.com/article/archive/pesticides-farmworkers-agriculture. Accessed November 2022.

Haidt J. 2022. Why the past 10 years of American life have been uniquely stupid - It's not just a phase. The Atlantic Monthly. May. Pp. 54–66.

Harker KN, O'Donovan JT, Blackshaw RE, Beckie HJ, Mallory-Smith C, Maxwell BD. 2012. Our view. *Weed Science*. **60**: 143–144.

Holthaus G. 2009. *From farm to the table: What all Americans need to know about agriculture*. University Press of Kentucky. 363 p.

Jordan N, Schut M, Graham S, Barney JN, Childs DZ, Christensen S, *et al*. 2016. Transdisciplinary need research: New leverage on challenging weed problems? *Weed Research* **56**(5): 345–358.

Kierkegaard S. 1995. Loves hidden life and its recognizability by its fruits. P-5. In: *1847 Works of Love*. Original publication. Princeton University Press, Princeton, NJ, 525 p.

King J. 1991. A matter of public confidence. *Agriculture. Engineering* **72**(4): 16–18.

Kolbert E. 2022. Testing the waters-should the natural world have rights? The New Yorker April 18 pages 16–19.

Lemonick MD. 2006. Are we losing our edge? *TIME*. 22: 30–33.

Logan WB. 1995. Dirt — *The ecstatic skin of the earth*. Riverhead Books, NY. 202 p.

Mayer A and Mayer J. 1974. Agriculture, the Island empire. *Daedalus* **103**: 83–95.

MacLaren C, Storkey J., Menegat A., Metcalfe H., Dehnen-Schmutz K. 2020. An ecological future for weed science sustained crop production and the environment. A review. *Agronomy for Sustainable Development*, **40**(4): 1-29. https://doi.org/10.1007/s13593-020-00631-6

Marshall EJP. 2019. Reflections on 14 years as Editor-in -Chief. *Weed Research* **59**:1-4

Mill John Stuart. 1859. *On Liberty. 1865*. Longman's, Green, and Co. London.

Montgomery DR., 2007. Dirt — *The erosion of civilizations*. University of California Press, Berkeley, CA. 285 p.

Morgan PA, Peters SJ. 2006. The foundations of planetary agrarianism. Thomas Berry and Liberty Hyde Bailey. *Journal of Agriculture Environment Ethics* **19:** 443–468.

Moss SR. 2008. Weed research: is it delivering what it should? *Weed Research* **48**(5): 389–393.

Nash R. 1977. Do rocks have rights? The Center Magazine. Center for the study of democratic institutions. *Santa Barbara*, CA. **7**: 2–12.

Neve P, Barney JN, Buckley Y, Cousens RD, Graham S, Jordan NR and 29 co-authors. 2018. Reviewing research priorities in weed ecology, evolution and management: a horizon scan. *Weed Research* **58**(4): 250–258.

Niebuhr R. 1932. *Moral man in an immoral society: a study in ethics and politics*. Westminster John Knox press. Louisville, Kentucky. 284 p.

Roberts C. 2024. Fruits and vegetables loaded with pesticides. Consumer Report.s April 18, 2024. https://www.theguardian.com/environment/2024/apr/18/what-is-%20pesticide-safety-organic-fruits-vegetables.%20Accessed%20April%202024.

Sachs JD. 2005. *The end of poverty: Economic possibilities for our time*. The Penguin Press, New York, NY. 396 p.

Sen A. 1999. *Development as freedom*. A. A. Knopf, New York. 366 p.

Shand H and Wetter KJ. 2006. Shrinking science: an introduction to nanotechnology. pp. 78–95. In: Starke, L. (Ed.), State of the World – 2006. W.W. Norton & Co., New York.

Specter M. 2016. Rewriting the code of life. *The New Yorker*: 34–43.

Stone C. 1972. *Should trees have standing? Toward legal rights for natural objects*. William Kaufman, Inc. Los altos, CA. 101 p.

Swanton CJ. 2022. Weed science and the clock of the long now. *Weed Science* **70**(4): 369.

Thompson PB. 1995. *The spirit of the soil*. New York, NY, Routledge. 196p.

Thompson PB. 1989. Values and food production. *Journal of Agricultural and Environmental Ethics* **2**: 209–234.

Ward SM, Cousens RD, Bagavathiannan MV Barney JN, Beckie HJ, Busi R, and 20 others. 2014. Agricultural weed research: a critique and two proposals. *Weed Science* **62:** 672–678.

Westwood J. Charudattan RH, Duke SO, Fennimore SA, Marrone P, Slaughter DC, Swanton C, and Zollinger R. 2018. Weed management in 2050: perspectives on the future of weed science. *Weed science* **66**(3): 275–285.

William RD, Ogg A, Rabb C. 2001. My view. *Weed Science 49:* 149.

Wyse DL. 1992. Future of weed science research. *Weed Science* 6, 162–165.

Young S L. 2020. A unifying approach for IWM. *Weed Science* **68**:435-436.

Zimdahl RL and Holtzer TO. 2016. The ethical values in the U.S. agriculture and foodsystem. *Agricultural and Environmental Ethics* **31**(6): 751–753. https://doi.org/10.1007/s10806-018-9753-4.

Zimdahl RL. 2022. *Agriculture's ethical horizon*, 3rd. Elsevier, Inc., San Diego, CA. 318 p.

Endnote

The general principle of utilitarian ethics is: actions should be evaluated on the basis of their consequences that maximize happiness and well-being while minimizing harm/suffering for all affected.