Agrochemical industry development, trends in R&D and the impact of regulation

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Abstract

Over the last 20 years the share of the crop protection market attributable to the leading markets (North America, EU-15 and Japan) that are the major focus of new active ingredient research and development (R&D) has declined. Greater growth has been recorded in developing markets, questioning the focus of current R&D strategy. R&D budgets within the major companies have seen a shift toward genetically modified (GM) trait development away from agrochemicals, such that the rate of new active ingredients entering development and subsequently being introduced has declined. As a result, the industry has become more reliant on older, off-patent chemistry, although the availability of older products has been affected by re-registration requirements, particularly in the EU. Current criteria often preclude the registration of broad-spectrum agrochemicals, resulting in many new active ingredients being single site active, which is perceived to increase the potential for resistance development, particularly for herbicides, although this is not always the case.

Keywords: agrochemical; R&D; registration; GM traits; hazard; risk; resistance; strategy

1 INTRODUCTION

Since 2014 the agrochemical industry has encountered a period of downturn affected by low crop prices and poor farm profitability. At the same time increasing regulation has made the introduction of new chemistry increasingly challenging, particularly in the EU where registration is now governed by hazard rather than risk. This has led to companies contemplating alternative technologies for crop protection, including biologicals/bio-stimulants, GM crops, precision agriculture, manipulation of the microbiome etc. The need to address these alternative technologies and the downturn in the chemical crop protection sector have resulted in a significant degree of industry consolidation, which has considerably altered the competitive environment.

This paper addresses recent industry trends and the short-term outlook, the impact that regulatory and consolidation events have had on new active ingredient development and introduction, and the availability of technologies in the EU in comparison with the USA and the rest of the world. Resistance development has sustained the need for new solutions, but rising costs and regulation/legislation have limited farmers’ access to some technologies. The key sectors driving growth in the crop protection sector will be discussed as well as current trends in research and development (R&D).

The crop protection market from year to year is affected by many variables, the most important being:

(1) crop prices and farmer wealth: a weak farm economy results in fewer agrochemical purchases, the use of lower cost product, reduced application rates, a shift from preventative treatments to rescue applications if required etc.

(2) weather: drought, affecting weed growth and pest and disease pressure; flooding affecting crop viability

(3) planted areas: related to demand, crop rotations and prices/profitability, often in reaction to the previous year’s harvest

(4) increased applications in developing markets when economic conditions allow

(5) technology: replacement with GM seed solutions, new methods for weed/pest/disease control

(6) regulation: removal of what may have been low cost and effective treatments from the market

(7) resistance: enforcing a shift to newer, often higher priced alternatives.

Figure 1 shows that from 2009 to 2014 the crop protection market enjoyed a period of significant growth fuelled by high demand in developing markets resulting in strong crop pricing and agrochemical purchasing and usage. The period also benefited from relatively stable weather conditions and exceptional pest outbreaks, notably Helicoverpa in Brazil, which resulted in increased application of soybean insecticides.

From 2014 to 2017 weather conditions were not so favourable, with El Nino resulting in dryness in Brazil and variable monsoons in Asia. Despite adverse weather, the usage of GM crops utilising higher quality germplasm resulted in crop yields in the Americas being sustained. This, building on excess crop production in 2014, resulted in rising crop stocks and falling prices such that...
the crop protection market fell into a slump, with the first signs of recovery being seen in 2018. This slump, along with a re-positioning of company strategies, heralded a significant round of corporate consolidation within the agrochemical and seeds industries, with Bayer acquiring Monsanto, ChemChina acquiring Syngenta and Dow merging with DuPont resulting in the formation of Corteva. Anti-trust requirements to allow these transactions to take place resulted in much of Bayer’s seed and trait operations and some agrochemicals being divested to BASF, making that company into a significant competitor in the seeds industry, DuPont having to divest its agrochemical R&D assets, including research products, to FMC, and Syngenta and Adama having to divest a range of agrochemicals mostly to Nufarm and Amvac. The aim of the required DuPont divestment was to sustain the number of companies active in new agrochemical R&D, the need for continuing innovation to counter the burgeoning issue of resistance development being recognized. However, as a result of these moves the agrochemical industry is now focused on fewer but larger companies, which gives these operations considerable strength in product supply and distribution.

Figure 2 shows the sales of the leading 15 agrochemical companies in 1998 and in 2017. In 1998, there was a slow drop off in sales between the leading company and that ranked in fourth position, with the companies ranked between fourth and tenth all achieving similar sales. With sales in 2017 ranked on a pro forma basis, taking changes due to acquisitions into account, the consolidation of the industry into the leading five companies is far more evident. As the cost of bringing a new active ingredient through R&D and to the market continues to increase, driven significantly by the increasing demands of regulatory bodies, it is evident that fewer companies currently have the financial acumen to sustain a broad basic agrochemical R&D programme compared to 20 years ago.

Figure 3 shows the share of the crop protection market between regions in 1998 and 2018. In 1998, North America accounted for 26.2% of the value of the global crop protection market; by 2018 this share had declined to 16.7%. In Europe the share has declined from 25.9% to 23.4%, but within those figures the loss of share in the more mature markets in the EU-15 has been more significant, with much of the growth being driven by Central and East European markets, particularly the more recent entrants to the EU. Whilst the proportion of the global market attributable to Asia has increased, much of this has been driven by developing countries with the larger markets in Japan, South Korea and Australia losing share. The most significant increase in share has been in Latin America, led by significant growth in Brazil and Argentina, the region not including any major mature markets that would depress overall growth figures. Within the current economic environment for agriculture (crop prices etc.) it appears...
that the Brazilian agrochemical market is now approaching maturity, so Latin American growth rates in the future may not be so impressive.

Figure 4 shows the local currency growth (CAGR, % p.a.) achieved in the leading 20 country markets worldwide in the last 5 years. The greatest growth has been achieved in developing markets, notably Argentina, Russia and Romania, whilst of the major markets only Spain, Italy, Australia, the USA and the UK recorded positive performances. It is notable that the leading two of these, Spain and Italy, are markets more driven by fruits and vegetables rather than the major row crops. Weakness in row crop prices has had a negative impact on the performance of the major markets where these crops account for a significant share.

The key reason that greater growth has been recorded in developing markets is that in many of these countries the number of applications of crop protection products is less than optimal to achieve full crop yield potential. As economies improve, the number of applications has been increasing, resulting in volume growth in the market. At the same time, many of these developing markets have been relying on older, lower cost chemistry. Again, as economies improve farmers have been trading up to more advanced but higher priced chemistries. The summation of this is value growth on top of volume growth. In the major mature markets, optimal levels of crop protection products are generally already being used, hence there is little room for volume growth. These markets are prone to the annual influences listed at the start of this paper, but generally only enjoy value growth from the replacement of older chemistries with newer more costly solutions, often in response to either resistance development or regulatory action.

The key focus of agrochemical new product development has generally been the high-value mature markets, but with the increasing share attributable to what have been viewed as developing markets, this may alter. There are a number of major factors that affect agrochemical R&D:

1. Rising costs and requirements of regulatory bodies.
2. Resistance development and the opportunity for replacement chemistry.
3. Industry consolidation and number of companies involved.
4. Portfolio management, balancing replacement of older off-patent chemistry against R&D of novel chemistry.
5. Novel formulations as a means of patent protection for older products.
6. Shift in focus to GM crop solutions, particularly in the Americas. (a) Insect resistance and herbicide tolerance (genetic manipulation). (b) Gene silencing RNA interference (RNAi). (c) Gene deletion Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR).
7. Influence of alternative technologies and integrated pest management (IPM). (a) Biologicals. (b) Bio-stimulants. (c) Microbiomes.

Figure 5 shows the number of new agrochemical and GM traits achieving introduction each year since 1997. The agrochemical bars represent the number of new active ingredients achieving first introduction in each year. The trait bars represent the number of new insect resistance traits, herbicide tolerance traits or trait combinations being introduced in each year. The first trait introductions occurred in 1996 and it is evident that since that time the number of trait introductions has increased significantly. At the same time, the number of new agrochemical introductions has been falling. As stated above the shift to GM solutions is only one of many factors that affects agrochemical R&D; however, in markets in the Americas, where herbicide tolerance traits dominate the maize, soybean, cotton and canola sectors, the number of new herbicide introductions in these sectors has declined significantly. More recently there has been some recovery as weed resistance to glyphosate has become a significant issue.

Table 1 shows chemical/mode of action classes of agrochemistry ranked by average growth between 2012 and 2017. It can be seen clearly that succinate dehydrogenase inhibiting (SDHI) fungicides
(mostly pyrazole carboxamides), biological fungicides and insecticides, diamide insecticides (Rynaxypyr and Cyazapyr) and ketoenol insecticides (spirotetramat) have recorded the greatest growth. The date of first introduction is when the first member of each class was first introduced. Generally, the classes recording the greatest growth in sales are the more recently introduced, showing that new products from R&D are important in driving industry growth.

Whilst SDHI fungicides have been on the market for some time, it was not until second-generation products (generally based on pyrazole carboxamide chemistry) were introduced that usage of the group expanded, notably for fluxapyroxad (introduced in 2012), boscalid (2003), benzovindiflupyr (2013) and fluopyram (2012). Part of the success of these products is due to resistance development to the strobilurins (Septoria in cereals and Asian rust on soybeans), with the SDHIs offering control of these diseases.

Biological insecticides and fungicides have been on the market for some time, although the wish to reduce the usage of chemicals and the drive towards IPM has recently resulted in significant growth in usage for these products, with a number of bacteria/viruses being introduced for disease and pest control. In many cases these biologicals have a relatively narrow spectrum of activity, but significant growth has been achieved in specific sectors (e.g. nematode control) and in combination with agrochemicals.

The commercial success of diamide chemistry has been well reported, offering a new mode of action for lepidoptera control, with Cyazapyr also having sucking pest activity. Again, resistance to older chemistry created the need for these products although enhanced efficacy was also a major factor in their commercial success.

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![Figure 5. Number of new active ingredients and GM trait introductions. Source: AgbioInvestor](image)

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### Table 1: Crop protection product sector development

| Rank | Sector | Class | First Introduction | Sales 2017 $bn | CAGR 2017/2012 |
|------|--------|-------|--------------------|----------------|----------------|
| 1    | Fungicide | Succinate-dehydrogenase inhibitors | 1966 | 1.33 | 17.4 |
| 2    | Fungicide | Biologicals | 1942 | 0.13 | 14.2 |
| 3    | Insecticide | Biologicals | 1960 | 0.73 | 12.4 |
| 4    | Insecticide | Diamides | 2007 | 1.76 | 10.5 |
| 5    | Insecticide | Ketoenols | 2003 | 0.36 | 7.9 |
| 6    | Insecticide | Other Insecticides | 1945 | 0.96 | 7.1 |
| 7    | Herbicide | PPO | 1969 | 1.51 | 6.4 |
| 8    | Herbicide | Thiacarbamates | 1957 | 0.20 | 5.3 |
| 9    | Fungicide | SBI - Other azoles | 1970 | 1.09 | 4.9 |
| 10   | Insecticide | IGRs: Others | 1985 | 0.32 | 4.3 |
| 11   | Fungicide | SBI: Others | 1969 | 0.08 | 3.5 |
| 12   | Fungicide | Anilinopyrimidine | 1993 | 0.16 | 2.8 |
| 13   | Herbicide | VLCFA Inhibitors | 1965 | 2.26 | 2.5 |
| 14   | Herbicide | ACCase Inhibitors | 1975 | 1.63 | 2.5 |
| 15   | Insecticide | Miticides | 1964 | 0.58 | 2.2 |
| 16   | Herbicide | Synthetic Auxins | 1945 | 2.24 | 2.0 |
| 17   | Herbicide | ALS: Others | 1992 | 1.17 | 1.7 |
| 18   | Fungicide | Contact: EBDC | 1943 | 1.15 | 1.6 |
| 19   | Fungicide | Strobilurins | 1996 | 2.95 | 1.3 |
| 20   | Insecticide | Fermentation products | 1965 | 1.68 | 1.0 |

Source: AgbioInvestor.
position in the sucking pest control market, and on some crops created a market for insecticidal seed treatments. However, regulatory action due to suspected issues regarding pollinator safety limited the usage of the products, notably in the EU, but also in parts of Canada and on cotton at flowering time in Brazil. As a neonicotinoid replacement, spirotetramat gained significant sales for sucking pest control following foliar applications. A number of new sucking pest insecticides have subsequently reached the market, although none as yet appear to have the same seed treatment efficacy as the neonicotinoids. In this case regulatory action has been a driver of R&D activity, but overall the farmer has fewer options, notably in the seed treatment area.

Figure 6 shows the value of each of the major sectors of the insecticide market in 2012 and 2017. The classes are ordered (x axis) by year of first introduction for the initial member of the class. The decline in sales recorded by the nicotinamides (including the neonicotinoids) and pyrazoles (including fipronil) can clearly be seen, both classes having been restricted by EU pollinator safety regulations. At the same time growth in the Ketoenol sector (neonicotinoid replacement) and diamide (new mode of action for lepidoptera control) is clearly evident.

It is in the EU where the impact of regulation on agrochemical availability has been the greatest. EU Council Directive 91/414 introduced the need to re-register existing agrochemicals under current day criteria, and this was enhanced by Regulation 1107/2009 that changed the basis of registration criteria to be governed by hazard rather than risk. It also introduced the concept of ‘comparative assessment and replacement by safer alternatives’. This resulted in development of a list of agrochemicals already registered in the EU that are deemed to be ‘candidates for substitution’. Agrochemicals appear on this list if they contravene two of three criteria: persistence, bioaccumulation or toxicity. The registration of each agrochemical has to be reassessed every 10 years and to remain on the market a product has to satisfy the new registration criteria. At that time alternatives to the candidates for substitution will be sought. It is the choice of existing registrants if they wish to continue to support a molecule through this re-registration process. Agrochemicals can leave the market if either they are not granted re-registration or if they are not supported by the existing registrants.

Figure 7 shows by decade when the agrochemicals were first introduced and the proportion of those on the market somewhere in the world in 2018 that are currently available in the EU and USA. Clearly not every agrochemical is registered in every country, for example there are no major cotton, rice or sugarcane markets in the EU, so fewer agrochemicals for these crops will be registered in this region. Of the products first introduced in the 1950s and still on the market in 2018, around 80% are available to farmers in the USA, but only just over 30% to farmers in the EU. The dotted line shows the proportion that will be available in the EU if all the products that are candidates for substitution lose their registrations. This is not thought likely but to date most of the few candidates for substitution that have been through re-registration are no longer on the market. The review of candidates for substitution is not expected to have a major impact on the number of older products on the market, as many of these were removed in the first round of re-registration, but it could have significant impact on the number of agrochemicals available in the EU that were introduced in the 1980s and 1990s.

The US Environmental Protection Agency (EPA) runs a registration system governed by risk and operates a registration review programme similar to that in the EU. Most existing agrochemicals are now under assessment, but as yet few rulings have been made and clearly the criteria for continued registration are somewhat different. It could be anticipated that a number of older chemistries will be restricted in the US market when registration reviews are complete, but the number of products potentially removed is not expected to be as great as in the EU due to the use of a scientific risk-based assessment system.

An example of the impact of EU regulation on the market is in the cereal herbicide market. Grass weed control in small grain

![Figure 6. Crop protection insecticide sector development. Source: AgbioInvestor](image-url)
cereal crops is technically challenging due to the similarity of the weeds to the crop, hence herbicides need to be highly specific. Re-registration of older agrochemicals has resulted in the removal of a number of agronomically important herbicides from the market, most notably pre-emergent products such as atrazine, trifluralin and isoproturon. This has pushed the market toward post-emergence grass weed control, where there are effectively only two modes of action available: acetolactate synthase inhibition (ALS) and acetyl-coenzyme A carboxylase inhibition (ACCase), both of which suffer significant weed resistance issues. The impact of this has been to push the market toward herbicides that control both grass and broadleaved weeds (although often not with the same efficacy for grass weed control as specific grass weed herbicides). Some of the herbicides that have benefited from this are now candidates for substitution, hence the number of solutions available to farmers is likely to be further restricted.

Clearly this creates an opportunity for new products from R&D in what is a very technically challenging area, but the strict EU hazard-based system is also seen as being detrimental to the development of new active ingredients for the EU market. It is evident that a smaller number of agrochemical active ingredients currently in R&D are focused on introduction in the European market in comparison with historical rates. If in research a potential agrochemical exhibits any persistence, bioaccumulation or toxicity effects then it is unlikely the compound would be progressed for development for the EU market as there is a significant likelihood that it would not achieve registration. However, if such an agrochemical were in development for the US market, and any persistence, bioaccumulation or toxicity issues were deemed to be within the boundaries of acceptable risk, then the compound may well progress to development, registration and commercial launch.

Figure 8 shows the number of weed species that have developed resistance to each class of herbicide by class and year of introduction. Source: Heap, I. The International Survey of Herbicide Resistant Weeds. Online. Internet. Tuesday, August 13, 2019. Available www.weedscience.org and AgbioInvestor.
chemistry against the year when the first member of that chemical class was introduced. For example, 160 weed species have developed resistance to ALS herbicides, the first of which was introduced in 1982. Other single-site active herbicide classes are also subject to weed resistance development, notably ACCase herbicides and glyphosate. However, other single-site active classes, notably 4-hydroxyphenylpyruvate dioxygenase (HPPD) inhibitors and protoporphyrinogen oxidase (PPO) inhibitors, have suffered only limited resistance, whilst significant resistance has developed to older less specific herbicide classes, notably the triazines and ureas.

Figure 9 shows the value of each of the major sectors of the herbicide market in 2012 and 2017. It clearly shows the importance in terms of sales of the newer classes of herbicide chemistry, notably ALS, HPPD, ACCase, PPO and inhibitors of very long chain fatty acid (VLCFA) synthesis as well as the amino acids (glyphosate and glufosinate). The impact of resistance can clearly be seen in the reduction in sales between 2012 and 2017 suffered by the

Figure 9. Crop protection herbicide sector development. Source: AgbioInvestor.

Figure 10. Crop protection fungicide sector development. Source: AgbioInvestor.
amino acids and sulfonylureas, although ACCase herbicides have seen an increase. The continuing importance of older classes, notably the triazines and synthetic auxins, can be seen, with both classes recording an increase in sales over this period. The synthetic auxins include dicamba and 2,4-Dichlorophenoxyacetic acid (2,4-D), both of which should record further sales growth with the introduction of Xtend (dicamba tolerance) and Enlist (2,4-D tolerance) traits.

Figure 10 shows the value of each of the major sectors of the fungicide market in 2012 and 2017. Growth of the SDHI class is clearly evident, as discussed earlier, the products taking share from the strobilurins due to resistance issues. Despite this the strobilurins continued to record an increase in turnover. Resistance has also been an issue for triazole chemistry, with a number in this class also being candidates for substitution in the EU, which could affect sales performance in the future. The main beneficiary from this is likely to be Sterol Biosynthesis inhibitor (SBI) other azoles, notably prothioconazole and the more recently introduced mfenfri fluconazole. However, the importance of older chemistry, notably contact products, ethylene bisdithiocarbamates (EBDCs) (mancozeb) and inorganics (copper and sulphur), is also evident as these products are often an important part of resistance avoidance strategies.

2 MARKET OUTLOOK

Figure 11 shows two growth phases in the performance of the agrochemical market in real terms, as close as possible to volume when analysing from a global perspective. Historical data is converted to real terms as potential currency and price movements, which can fluctuate widely, are not taken into account in the forecast.

As a result of poor farm economics and the introduction of GM crops, the agrochemical market underwent a period of weakness in the late 1990s, which was followed by a period of steady growth from 2006 to 2010. During this period crop prices and farm incomes steadily improved, resulting in increased agrochemical usage.

The industry saw a period of exceptional growth from 2010 through to 2014, a period of high demand for crops, strength in commodity markets and rapid expansion in developing markets, notably Brazil, but also India and China. This growth was exacerbated by the Helicoverpa outbreak, which boosted insecticide sales in Brazil, but which came to an end in 2014.

The 2014 to 2017 period was marked by El Nino driven adverse weather, an abundance of crops resulting in lower prices and a weakening farm economy, the Brazilian market reaching maturity and then suffering as lower crop prices reduced farm incomes whilst the Helicoverpa outbreak was brought under control, resulting in fewer insecticide sales, and GM crop areas increased.

The first signs of recovery from this slump were seen in 2018. The key factors likely to impact the performance of the crop protection market in the immediate term are as follows:

- Crop production/stocks likely to remain high
- Improved seed quality
- Further GM adoption
- Volume growth in developing markets
  - Central/East Europe
  - Developing Latin America
  - East Asia
- R&D
  - Further regulatory pressure on older chemistry
  - Less new chemistry being introduced
  - Resistance drives need for new solutions
- Distribution
  - Impact of precision Agriculture (Ag)/‘big data’
  - New purchasing/delivery options
  - Farmers seeking best service but lower cost options
Crop prices and farm incomes are the key determinant for agrochemical market performance as producers have to be able to afford the technology. A major factor affecting crop prices is the level of production in the previous year, which is greatly affected by the weather. However, GM traits are generally incorporated into seeds with the best germplasm. As a result, the average quality of seed planted in regions that have accepted GM technology has improved dramatically, and because of this crop yield is more protected from adverse weather in these countries. Consequently, adverse weather has not had as great an impact on crop stocks as may have been expected so crop prices have remained weak. With further adoption of GM crops, and as a result sustained crop yields, it is likely that crop prices will remain depressed for some time.

It has been shown that crop protection market growth is greater in developing countries where the potential for volume growth exists. This is expected to continue in the immediate future until the markets in these countries start to reach maturity.

Following a period of industry consolidation, companies generally look to how they interact with distribution as a means to maximize market share. Digital agriculture is providing big data and market intelligence to companies, potentially altering how they interact with conventional agrochemical distribution. New companies have emerged to support farmers and provide a new route for agrochemical supply, further challenging conventional distribution. Against this background, a fragile farm economy results in farmers seeking the lowest cost options with the best service, opening the door to different distribution models. This could have a significant impact on agrochemical market value.

In-seed solutions for crop protection have already had a significant impact on agrochemical usage through genetically manipulation to offer herbicide tolerance and insect resistance. Further related technologies, i.e. RNAI (gene silencing) and CRISPR (gene deletion), offer enhanced and alternative technologies for achieving crop protection, which could have a negative impact on agrochemical market development.

However, overall it is believed that a more holistic view to crop protection is likely to be the most successful strategy, as many of these apparently competing technologies are in fact symbiotic and their use in combination is likely to provide the most positive solution.

3 CONCLUSION

This analysis has shown that the number of new agrochemical active ingredients entering the market has declined in recent years, in some ways due to R&D budgets being diverted to other crop protection technologies, notably GM seed, biologicals and other alternative technologies. Consolidation has resulted in the concentration of the industry into fewer, but larger, companies, but overall the number involved in the R&D of new active ingredients is smaller.

The need for new active ingredients has been demonstrated due to the increasing impact of weed and disease resistance, with insect resistance also a significant factor. It has been shown how resistance development creates opportunities for new products, particularly in the fungicide sector with the strobilurins, SDHIs and triazoles, but also in the herbicide sector with moves from the ALS herbicides and glyphosate to VLCFA, HPPD and PPO herbicides.

The number of active ingredients currently on the market has declined in the EU due to the impact of re-registration leading to older chemistries either no longer being supported or not being re-approved. This factor is expected to increase with the change in registration criteria to a hazard-based system and no longer based on risk. Sixty active ingredients have been listed as candidates for substitution and could well be restricted or leave the market when their re-registration is assessed. The hazard-based system also makes the criteria for new active ingredient registration more onerous and is believed to have resulted in fewer new active ingredients being developed for the EU market.

The outcome of this is that farmers in the EU have access to far fewer existing agrochemicals than are available in other markets, notably the USA, whilst the stream of replacement technology is also slowed. The EPA also operates a registration review programme that could restrict access to older chemistry in the USA, but as this is governed by risk rather than hazard it is far less likely that as many agrochemicals will be restricted or removed from the market as in the EU.

It has been shown that regulatory action, particularly with the neonicotinoids in the EU, has significantly altered product usage. Whilst there is less new chemistry being introduced, the fastest growing chemistry sectors are all driven by recent agrochemical introductions, indicating the potential commercial success of R&D.

Market dynamics have altered in the last 20 years, with greater growth being recorded by developing markets driven by both volume and value growth, rather than by the larger mature markets where limited value growth from product substitution is the main growth driver. This suggests that the focus of R&D could change, with a greater emphasis on crops cultivated in these developing markets and away from the staple row crops cultivated in the major markets.

Whilst recently the industry has been in a slump, signs of recovery are now evident, leading to the expectation of a return to slower but steady growth. The challenge is to provide farmers with the tools to realize this potential and to provide a stable, high-quality food supply.

DATA SOURCES

AgbioCrop – published by AgbioInvestor.
AgbioSeed – published by AgbioInvestor.
Crop prices. Available: http://www.fao.org/giews/food-prices-tool/public/index.html.
Products in R&D. Compendium of Pesticide Common Names. Available: http://www.alanwood.net/pesticides/index.html.
Herbicide resistance. Heap, I The International Survey of Herbicide Resistant Weeds Online Internet. Available: www.weedscience.org [13 August 2019].
Crop Areas. Available: https://appsso.eurostat.ec.europa.eu.
Crop Areas: USDA World Agricultural production. Available: https://www.fas.usda.gov/data/world-agricultural-production.
Crop Stocks: https://www.usda.gov/oe/commodity/wadse.
Agrochemicals registered in the EU, EU pesticides database. Available: https://ec.europa.eu/food/plant/pesticides/pesticides-database/public/?event=activesubstance.selection&language=EN.
Agrochemicals registered in the USA, EPA pesticides database. Available: https://faspub.epa.gov/ apex/pesticides/?p=chemicalsearch.
Agrochemicals registered in the USA: National pesticide information retrieval system. Available: http://npispublic.ceris.purdue.edu/ppis/.
Candidates for substitution in the EU, European Commission Approval of active substances. Available: https://ec.europa.eu/food/plant/pesticides/approval_active_substances_en.