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Review Paper

Atrazine and its Use

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Abstract - *Atrazine was registered for use in Switzerland in 1956 and in the US in 1958. Aytazine was first released for experiment station evaluations in 1957 and became commercially available in 1958. It quickly became the most popular of the triazines for its effectiveness against a wide spectrum of weeds in a range of conditions, including in dry soil. It has since become one of the most widely researched herbicides to date. It is chlorinated herbicide and most heavily used worldwide. It has been observed that their long-term, low-dose exposure are increasingly linked to human health effects such as immune-suppression, hormone disruption, diminished intelligence, reproductive abnormalities, and cancer. It has been detected in waterbodies. This paper is an attempt to review the use of atrazine worldwide.*

Keywords: *atrazine*, herbicide, pesticide.

Introduction

Today, atrazine is used in more than 60 countries around the world. The heavy use of atrazine growing in many developing countries, is largely confined to North America, Western Europe, Latin America, Japan, Australia, Africa, North and South America, Asia and the Middle East. Herbs compete the crops for water, nutrition and fertilizer and thereby contribute to major loss of economy. Without the use of herbicides, it would have been impossible to mechanize fully the production of cotton, sugar beets, grains, potatoes and corn.

Development of the triazines began in the early 1950s by J.R. Giegy, Ltd [1]. Commercial production of simazine started in 1956 at the Geigy Schweizerhalle plant near Basel, Switzerland. Smaller production units were placed in operation in Mexico, Brazil, and Australia. Worldwide there were soon 22 or more triazine plants, including atrazine production in the agricultural countries of Hungary, Czechoslovakia, Romania, and Yugoslavia. By 1981, Shell had built its own plant for atrazine. Agricultural use of atrazine has also been reported in South Africa, Australia, New Zealand, Venezuela, and in most European countries[2, 3].

Atrazine is considered to be one of the most well understood chemicals. Today, terbuthylazine remains an important herbicide in Europe, especially in corn and grape crops, and received a recent favorable science review during the EU's reregistration process[4].

In the United States, atrazine has been used for weed control in agriculture over the past 35 years. It is used on approximately 67% of all corn acreage, 65% of sorghum acreage and 90% of sugar-cane acreage and is also used on wheat, guavas, macadamia nuts, conifers and turf and for non-selective use along roads.([5,6, 7]. Atrazine is "one of the two most widely used agricultural pesticides in the U.S.[8] Farmers have used atrazine for over forty years for affordable, effective and safe weed control.

Atrazine (2-chloro-4-ethylamino-6-isopropylamino -1,3,5-triazine) is a selective triazine herbicide and the most heavily used agricultural pesticide in North America [9,10,11,12]. It is registered for use in agriculture as a selective pre- and post-emergence herbicide for controlling weeds in numerous crops, including corn (*Zeamays*), sorghum (*Sorghum vulgare*), sugarcane (*Saccharum officinarum*), soybeans (*Glycine max*),wheat (*Triticum aestivum*), pineapple (*Ananas comusus*), and various range grasses [2,13, 3]. It has been used on various crops like asparagus, bananas, citrus groves, coffee, conifer tree crop areas, forestry, fruit orchards, grasslands, grass crops, guavas, macadamia orchards, maize, oil palms, roses and vines, wheat (application to wheat stubble on fallow land following harvest), guava, macadamia nuts, hay, pasture, summer fallow, forestry or woodlands, conifers, woody ornamentals, Christmas trees, sod, and residential and recreational turf (parks, golf courses). Other crops treated with atrazine include grapes, and forestry products. It is also used on corn (field and sweet), wheat (application to wheat stubble on fallow land following harvest), Though it is by far most heavily used in agricultural regions, atrazine is also used to maintain residential lawns and recreational turf [1,14]. Given the specific nature of the turf uses, much of atrazine's use on turf is confined to Florida and the Southeast.[15]

It has also been used as a soil sterilant for airfields, parking lots and industrial sites and as an algicide in swimming pools. Recently, many of the uses which contribute residues to water have been reduced or eliminated.[16, 17, 5, 18, 9] Given the specific nature of the turf uses, much of atrazine's use on turf is confined to Florida and the Southeast.

It is used as a total herbicide on roads and public places as well as on uncultivated ground in combination with amitrol, bromacil, dalapon and growth promoters. Atrazine inhibits photosynthesis and other metabolic processes in plants. There are no natural sources of atrazine.

It is also used extensively away from the farm, in areas such as industrial sites, roadsides, ditch banks, irrigation canals, fence lines, recreational areas, lawns, railroad embankments, and power line rights-of-way. It removes undesirable plants that might cause damage, present fire hazards, or impede work crews. They also reduce costs of labor for mowing. It is also used to maintain residential lawns and recreational turf [1]. It has also been used as a soil sterilant for airfields, parking lots and industrial sites and as an algicide in swimming pools.

Atrazine controls broadleaf (dicot) weeds such as pigweed, cocklebur, velvetleaf and certain grass weeds. Selective control means that the target weeds are controlled, with little or no injury to the crop. Atrazine is well tolerated by actively growing corn and sorghum, which absorb and metabolize the herbicide and thereby detoxify it. Atrazine is widely used today because it is economical and effectively reduces crop losses due to weed interference. The compound is both effective, inexpensive and is well-suited to production systems with very narrow profit margins. Its use can also reduce or eliminate the need for inter-row cultivation in corn and sorghum fields. With nearly 6,000 studies on file at EPA and 50 years of on-farm use, experts have concluded that atrazine if used safely, does not cause adverse effects to reproductive systems, not affect genetic development, not cause birth defects, not affect chromosome structure, not estrogenic, not disrupt endocrine function and does not cause cancer in humans [19].

The compound is both effective and inexpensive, and thus is well-suited to production systems with very narrow profit margins, as is often the case with maize.

Properties

It is used as preemergence as water dispersed spray or in liquid fertilizers. It is formulated as an emulsifiable concentrate, flowable concentrate, water dispersable granular (dry flowable), soluble concentrate, wettable powder, granular, and as a ready-to-use formulation, flowable liquid, liquid, water dispersible granular formulations [20,21] . Atrazine has been classified as a Restricted Use Pesticide (RUP), due to its potential for groundwater contamination [22]. It is used as preemergence as water dispersed spray or in liquid fertilizers. Atrazine works by preventing photosynthesis.

It is produced from cyanuric acid chloride with ethylamine and isopropylamine. The reaction takes place successively in tetrachloromethane. All the atrazine produced is released into the environment. It is of particular concern to water supplies due to its popularity, relatively long half life (60 to 100 days) and because it is not strongly absorbed by soil (Koc = ~100). This pesticide is a white crystalline solid organic compound that is available in many forms as a dry flowable, flowable liquid, water dispersible granular liquid, and a wetable powder [23].

It is effective for weed control, relatively non-toxic to animals, and inhibits photosynthesis in susceptible plants. Photosynthesis is the process that occurs in green leaves and stems of plants, whereby light energy is converted to chemical energy (carbohydrates). Since 1990, atrazine has been classified in the United States as a restricted use pesticide (RUP) due to its potential to contaminate groundwater. The triazine group of herbicides, to which atrazine belongs, constitute the second largest group sold in the United States [24].

Uses

Atrazine can be applied to corn pre-plant, pre-emergence, or post-emergence, making it a very flexible herbicide. Atrazine can also be applied with irrigation water (chemigation) from center-pivot irrigation systems, although current regulations forbid this method. It can be applied by groundboom sprayer, aircraft, tractor-drawn spreader, rights-of-way sprayer, hand-held sprayers, backpack sprayer, lawn handgun, push-type spreader, and bellygrinder. It can be applied alone or combined other herbicides. Atrazine is used on over fifty different crops, including corn, which represented nearly 25% of total US crop acreage as of 2000 and is a significant export crop of China, Brazil, and Mexico [1].

Use of atrazine along with other herbicides are restricted in many countries due to concerns of ground water. As per EU directive 91/414, in most of Europian countries it has been withdrawn from the use but essential use provision allows its use to continue till 2007[25].

It provides cost effective long term control. Cyanazine mixed with low dose of atrazine is used for weed control in newly planted farm wood land. The use of atrazine may boost crop yields by anywhere from 6.5% to less than 1% [26]. One study reported that sweet corn treated with a mixed herbicide preparation including atrazine developed more carotenoids, suggesting that atrazine may potentially increase the nutritional value of one of the main crops it is used on [27].

The importance of atrazine to farmers is further demonstrated by the fact that a recent French ban on the use of atrazine has had serious economic and crop protection consequences, particularly for maize growers [28]. Its effect on yields has been estimated from 6% to 1%, with 3-4% being the conclusion of one review [26]. In another study looking at combined data from 236 university corn field trials from 1986–2005, atrazine treatments showed an average of 5.7 bushels more per acre than alternative herbicide treatments [29] Its use is controversial due to widespread contamination in drinking water and its associations with birth defects, menstrual problems, and cancer when consumed by humans at concentrations below government standards [30]. Although it has been excluded from a re-registration process in the European Union, it is still one of the most widely used herbicides in the world.

In 2004, the European Union (EU) banned the use of atrazine stating that current use patterns did not guarantee the protection of groundwater to ensure the drinking water standard of 0.1 µg/L could continually be met. Many individual European countries had banned its use years earlier. A 2001 estimate of pesticide usage in the United States was 2.3 billion kilograms. Conventional pesticides accounted for 0.4 billion kilograms of which herbicides comprised 62% usage. Atrazine's estimated 2001 annual usage in the agricultural sector was 34 to 36 million kilograms, ranking it as the second most used herbicide in the United States. About 76 million pounds of atrazine were applied in the United States in 2003. Atrazine and dozens of products containing atrazine were used on approximately 83 percent of Indiana's 2003 corn acreage at an average rate of 1.25 pounds of active ingredient per acre (ai/A). This amounts to almost 6 million pounds of atrazine applied to Indiana corn in 2003 [31]. Heavy rain following atrazine applications can result in runoff from farm fields into nearby streams and reservoirs[31]. Data from the U.S. Environmental Protection Agency (EPA) show that farming without atrazine would cost corn growers $28 per acre in lost yield and/or increased weed control costs. The agency estimates the total negative impact on corn, sorghum and sugar cane growers in the U.S. would exceed $2 billion if atrazine were not available [32].

Effective, broad spectrum weed control leads to high crop yields, Low treatment cost, Application flexibility: atrazine can be applied prior to, during or after planting the crop, or after crop emergence, so it fits a wide variety of cropping systems, Fits soil-saving conservation tillage systems. Low risk of crop injury. Important in management of weed resistance. Low potential for drift. It can be applied to crops before, during or after planting of the seeds, or even after the crop emerges [33].

Consumption

In 1976, 41 million kg (90 million pounds) were applied to 25 million ha (62 million acres) on farms in the United States, principally for weed control in corn, wheat, and sorghum crops. This volume represented 16% of all herbicides and 9% of all pesticides applied in the United States during that year [9, 34]. By 1980, domestic usage had increased to 50 million kg [2]. In Canada, atrazine was the most widely used of 77 pesticides surveyed [35].

The United States Environmental Protection Agency (EPA) [36] reported that since the 1980s, the annual use of all pesticides had been holding steady at 500 million kg of active ingredients. More specifically, 363 million kg of atrazine were applied between 1980 and 1990 in the USA alone [37].

In 1987, global use of atrazine is estimated at 70 to 90 million kg annually, although Germany banned atrazine in 1991[38]. Resistance to atrazine has developed in various strains of weeds typically present in crop fields sometimes in less than two generations [39, 40] suggesting that future agricultural use of atrazine may be limited.

In early 90's Atrazine was used on approximately 67% of all corn acreage, 65% of sorghum acreage and 90% of sugar-cane acreage and is also used on wheat, guavas, macadamia nuts, conifers and turf and for non-selective use along roads [5,6,9]. In 1995, conventional pesticide use in USA amounted to about 1.22 billion pounds, which was one fifth of the world's use of such chemical [41]. Herbicides are the pesticides used to remove weeds that would otherwise compete with the crop.

A total of 44,485 pounds of atrazine was used in California in 1993 for corn (62%), landscape (5%), rights-of-way (18%) and Sudan grass (8%). In 1995 the amount of atrazine used in California was 41,241 pounds [42].

Atrazine is commonly used in combination with other pesticides, including metochlor, cyanazine, Sethyl diisobutylthiocarbamate, alachlor, bromoxynil, and sodium chlorate terbuthylazine, S-metolachlor, and simazine[42]. Average rates of 1 to 2.5 pounds/acre are usually applied by ground boom application, but higher concentrations may be used under nonselective conditions. In 1995, 149–160x10^6 kg of atrazine was applied worldwide [43].

The Environmental Protection Agency estimated that 31–35 million kg (active ingredient) of atrazine were used annually in agricultural crop production in the United States in 1987, 1993 and 1995[44]. Among all the pesticides, herbicide production and its use was more than any other pesticides in the world [41]. Though herbicide use in India is insignificant compared to other countries in the World, the total intake of pesticide containing chlorine by an Indian is the highest [45]. In 2001, pesticides of 32 billion dollar have been marketed in the world, whereas in India it amounts Rs. 4,500 crore. In 2001 estimated annual use is between 64 and 75 million pounds [46].

Atrazine is a chlorinated herbicide and at present, it has been used in more than 80 countries and probably it is the most commonly used herbicide in the world [24]. It exhibits acute, chronic and phytotoxicity. It has been proved that atrazine contains mutagenic and carcinogenic agents also. Approximately three-fourths of all field corn and sorghum are treated with atrazine annually for weed control. Compared to the $3.00 per acre cost of Atrazine, Balance pro costs me over $10.00 per acre-an increase of $7.00 per acre in input cost.

In its 2003 Interim Reregistration Eligibility Decision, U.S. EPA said "The total or national economic impact resulting from the loss of atrazine to control grass and broadleaf weeds in corn, sorghum and sugar cane would be in excess of $2 billion per year if atrazine were unavailable to growers." In the same report, it added the "yield loss plus increased herbicide cost may result in an average estimated loss of $28 per acre" if atrazine were unavailable to corn farmers [25, 32].

In 2004, the worldwide consumption of pesticides is about two million tonnes per year, of which 24% is consumed in the USA alone, 45% in Europe and 25% in the rest of the world. India's share is just 3.75%. The usage of pesticides in India is only 0.5 kg/ha, while in Korea and Japan, it is 6.6 and 12.0 kg/ha, respectively. Currently, the pesticides are being used on 25% of the cultivated area. Out of the total consumption of pesticides, 80% are in the form of insecticides, 15% are herbicides, 1.46% is fungicide and less than 3% are others. The worldwide consumption of herbicides is 47.5%, insecticides are, 29.5%, and fungicides, 17.5% and others account for 5.5% only. The consumption of herbicides in India is probably low, because weed control is mainly done by hand weeding. In addition to public health and agricultural use, pesticides also find their use in other sectors as well. India was the second largest manufacturer of basic pesticides in Asia. It ranked 12th globally. Consumption of pesticides in India is still very low, about 0.5 kg/ha of pesticides against 6.60 and 12.0 kg/ha in Korea and Japan, respectively. It has been observed that their long-term, low-dose exposure are increasingly linked to human health effects such as immune-suppression, hormone disruption, diminished intelligence, reproductive abnormalities, and cancer [47].

Total annual domestic use averages approximately 76 million pounds of active ingredient. Crops with the highest percent crop treated are field corn (75%), sugarcane (76%), sorghum (59 %), sweet corn (processed) (86 %), and sweet corn (fresh) (50 %). In terms of pounds applied, corn (86%), sorghum (10 %), and sugarcane (3 %) account for the greatest use. Less than 1 % of atrazine is applied for forestry, turf, and other uses. Atrazine was used on 61.7% of conventional tillage corn in 2004 and 84.1% of conservation tillage corn. If Atrazine and simazine herbicides were not available, farmers could be expected to increase tillage to control weeds in the absence of effective herbicides. Approximately 76.4 million pounds are applied each year. Usage on corn accounts for approximately 86% of total U.S. domestic usage (in pounds), followed by sorghum at 10% and sugarcane at 3% (all other uses take up the remaining 1%). About 75% of the field corn acreage grown in the U.S. is treated with atrazine [48].

Advantage of tillage system

Atrazine is valuable in conservation tillage systems in corn. They provide excellent residual control and are not tightly adsorbed to surface crop residue. They are washed easily from residue to the soil. Atrazine also provides postemergence activity, helping to control emerged weeds. Conservation tillage reduces soil erosion by as much as 90 percent, compared to systems using intensive tillage. Reduced soil erosion decreases sedimentation in nearby waterways, which helps protect existing aquatic ecosystems. Conservation tillage, buffers and filter strips protect water quality by reducing the runoff of crop nutrients and pesticides applied to farm fields by 70 percent or more. Conservation tillage cuts farmers' overall use of fuel. This reduces exhaust emissions from agricultural equipment and decreases agriculture's consumption of non-renewable fossil fuels. Conservation tillage helps build organic content in the topsoil by keeping a layer of crop residue near the soil surface. As organic matter increases, carbon dioxide from the atmosphere is sequestered in the soil, reducing global warming concerns. Switching to no-till promotes the storage of about 600 pounds of carbon in an acre of soil each year. No-till fields provide better wildlife habitat. For example, in a North Carolina study, quail chicks found their daily food needs in one-fifth the time in no-till fields, compared to tilled fields [48].

Average use of atrazine in 2002 shown in Figure 1.

Regulation

Science and regulatory reviews conducted by the United Kingdom for the European Union in 1996 and 2000 [50, 51] in Australia in 1997 and 2004, the International Agency for Research on Cancer (IARC) in 1999, and the US Environmental Protection Agency [25] all support the safety and continued availability of atrazine for weed control.

In 2006, after a comprehensive science review of chlorotriazines, the USEPA determined 'there is reasonable certainty that no harm will result to the general US population, infants, children, or other major identifi able subgroups of consumers, from the use of simazine, atrazine, and propazine[25].

Indian scenario

India has an agrarian economy, where the 1012.4 million population is dependent on agricultural commodities from 124.07 million hectares cropped area cultivated by 110.7 million producers [52].Three decades back, intensive and extensive cultivation of high yielding varieties of crops were introduced in India to increase food grain production to meet the exploding population. Demand for chemical pest control and resulting negative externalities have expanded greatly during the last four decades [53]. Use of pesticides in India began in 1948 when DDT was imported for malaria control and BHC for locust control. India started pesticide production with manufacturing plant for DDT and benzene hexachloride (BHC) (HCH) in the year 1952. In 1958, India was producing over 5000 metric tonnes of pesticides. Currently, there are approximately 145 pesticides registered for use, and production has increased to approximately 85,000 metric tonnes [47].

Previously, this pest only seriously affected rabi crops such as chickpea and was commonly known as the gram pod borer. Similar outbreaks have been reported for other insects: Whitefly in 1984-85 and 1985-86 in South Indian states, and tobacco caterpillar in 1977-78 and 1979-80 in the states of Tamil Nadu and Gujarat [54] and more recently, coconut mite, Aceria guererronis (Eriophyidae: Acarinae).[55]. India now produces 47,020 metric tons of pesticide.

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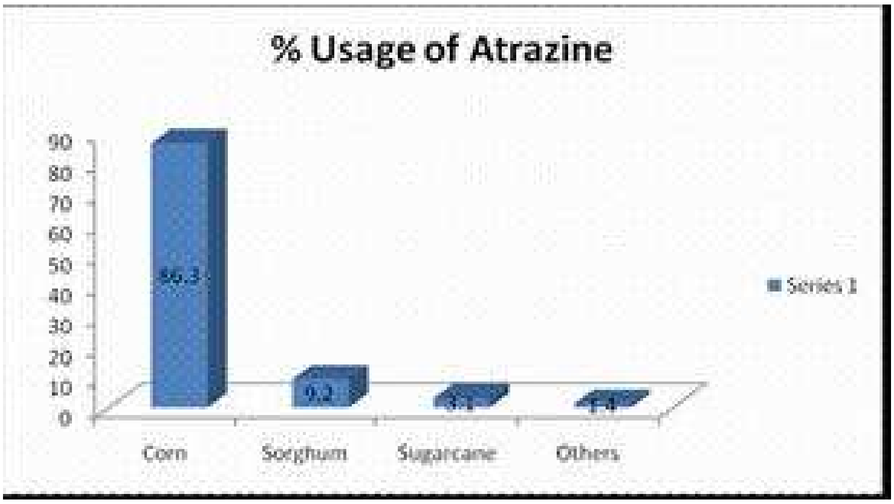

Figure 1: Average atrazine use by crop in the United States for 2000–2002[49]