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Status of Pesticide Usage on Golf Courses in Korea and Optimal Pesticide Usage Plan

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Abstract: Risks to human health and the environment owing to pesticide usage have arisen interest, increasing the demand for reducing pesticide consumption used on golf courses. However, standard guidelines or manuals for reducing pesticide usage on golf courses in Korea are lacking. Herein, the trends of pesticides on golf courses were investigated, and the optimal pesticide usage plan was proposed for continuous pesticide reduction. In 2019, there were 539 golf courses in Korea. With the increasing number of golf courses in 2010–2019, pesticide usage increased continuously. Fungicides accounted for more than half the pesticides used, followed by insecticides and herbicides. Except for golf courses that do not employ chemical pesticides, pesticide usage per unit area varied in the range of 0.02–65.81 kg ha^{-1} (average of 6.97 kg ha^{-1}). In the US, best management practices and integrated pest management (IPM) have been stipulated and are operational in each state for pesticide management in golf courses, recognizing chemical pesticide usage to be the last approach for pest control and turf health maintenance. Considering that Korea globally ranks 10th in the number of golf facilities and courses, the establishment of IPM practices suitable for domestic conditions is essential.

Keywords: best management practice; integrated pest management; pyramid tactic; resilience adaptive cycle; threshold

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1. Introduction

Golf courses are facilities that occupy the largest area among sports facilities and comprise greens, fairways, roughs, practice putting greens, and teeing grounds composed of natural or synthetic mown turfgrass and trees as well as parking lots and clubhouses [1]. Because golf courses must maintain high-quality turfgrass for optimal player performance and economic benefits, pesticides are mostly used for disease and insect pest control [2]. However, the extensive and continuous consumption of pesticides increases the operating cost of golf course management and the pollution load on the environment [3]. Therefore, interest in ecofriendly turfgrass management is increasing consistently, and research on minimizing pesticide usage is ongoing [4].

According to the Pesticide Control Act in Korea, pesticides contain chemicals that enhance or suppress the physiological properties of crops as well as fungicides, insecticides, and herbicides for controlling fungi, insects, spider mites, nematodes, viruses, weeds, and other pests [5]. Among pesticides, natural plant protection products (called biopesticides) are obtained using naturally derived microbes or organic/inorganic compounds as the active components. A total of 317 turfgrass pesticides have been registered in the Pesticide Safety Information System as of 2021, of which the numbers of fungicides, herbicides, insecticides, growth regulators, biopesticides, commercial mixtures (fungicides + insecticides), and others were 171, 92, 42, 5, 4, 2, and 1, respectively. Along with turfgrass, golf courses have trees for landscaping, and 170 tree pesticides were registered in the Pesticide Safety Information System, including insecticides (113), fungicides (42), herbicides (11), commercial mixtures (fungicides + insecticides) (2), and biopesticides (2) [6]. Since 2018, a prescription from a tree doctor has been required to use pesticides on trees. However, this approach involved complex issues such that not many registrations of tree pesticides have been made for different species or genera of trees, owing to which nonregistered pesticides were being prescribed and used [7].

Under the Pesticide Control Act, Water Environment Conservation Act, and Regulations on Surveying the Amount of Pesticide Use on Golf Courses and Test Methods, the quantities of pesticide usage and pesticide residues in soil and water are monitored twice yearly in golf courses in Korea [5,8,9]. Golf courses are managed based on pesticide residues and not pesticide usage, such as the pesticide management for food and agricultural products. Moreover, a fine is imposed on users using fatally or highly poisonous pesticides and those violating the guidelines for safe pesticide use. Besides Korea, other countries also do not regulate pesticide usage. However, in the US, golf course management is performed according to the manual of the best management practices (BMPs), and pesticide residues are primarily managed in the water quality [10]. In Japan, pesticide residue investigations are performed on golf course drainages and surrounding water resources [11]. There are interim water quality standards for the maximum residue limits of 192 pesticides in Korea.

Without direct regulations on the quantity of pesticides used on golf courses, interests in ecofriendly golf courses, including reduced pesticide usage, and activities to certify ecofriendly golf courses have increased in private sectors in Korea and abroad. In the UK, the Golf Environment Organization (GEO) has been offered a sustainable golf course certification based on the self-assessment and field verification of GEO certified, the nature (habitat, biodiversity, turfgrass, and pollution prevention), resources (water resources, energy, and materials), and community (volunteer activities and communication); approximately 100 golf courses globally have received this certification. Similarly, Audubon International—a private organization in the US—has been provided an education and a certification program that helps protect the environment of the golf course, which are guided through projects in the categories of environmental planning, wildlife and habitat management, chemical use reduction and safety, water conservation, water quality management, and outreach [12]. In 2012, the Korean Ministry of Environment tried to establish criteria for building and evaluating ecofriendly golf courses, and they considered giving bonus points during assessments if pesticides were used at a level of 2.5 kg ha^{-1} a.i. or less [13]. However, this guideline was abolished in 2015, and some articles remained in the Environmental Impact Assessment. Currently, the media organization, Leisure News, has selected 20 ecofriendly golf courses biennially based on comprehensive assessment in courses, clubhouse affinities, natural affinities, pesticides use, customer services, ecofriendly golf course award histories, etc. [14].

In March 2020, after the World Health Organization declared COVID-19 as a pandemic, an increasing number of Korean golf players who used to play overseas as well as young golf players started using Korean golf courses. Thus, the interest in golf and golf courses increased, consequently leading to an increase in the green fee in Korean golf courses [15]. This has induced a demand for reducing the quantity of pesticides used on golf courses considering the human health risks and for assessing environmental impacts by pesticides. However, guidelines or manuals for limiting the quantities of pesticides used on golf courses are currently lacking.

This study aims to identify the latest status of pesticides in Korean golf courses and propose the optimal pesticide usage plan for the continual reduction in pesticide usage in the future.

2. Materials and Methods

2.1. Information Regarding Pesticides on Golf Courses

The data on the status of golf courses and pesticides used therein were collected from the Soil Groundwater Information System of the National Institute of Environmental Research. The study employed the data of the quantity of pesticides used based on the number of golf course facilities in Korea, total area of golf courses, areas using pesticides of the total golf course area, and pesticide usage based on active ingredients (amount of pesticide actually used × active ingredient contents in used pesticide) instead of only the actual quantity. Only chemical pesticides registered in the Pesticide Safety Information System were considered for statistics and biopesticides and organic agricultural materials were excluded. SigmaPlot 14 (Systat Software Inc., San Jose, CA, USA) was used for statistical analysis and visualization. Dynamic curve fitting was used for regression analysis between the obtained data, and the total number of fittings and the maximum number of iterations were set to 200.

2.2. Distribution Map of the Quantity of Pesticide Usage Per Unit Area of Korean Golf Courses

The quantum geographic information system (QGIS; ver. 3.16.13) was used to prepare a map of the quantity of pesticides used per unit area in all 539 Korean golf courses (as of 2019). The QGIS is a representative free open-source program that undergoes continuous development through a network of users [16]. The class intervals for pesticides used per unit area were set based on a quantile method (i.e., the number of ratings). An increase in the intensity of the color of the circle on the map from white to red indicates that the quantity of pesticides used per unit area also increases.

2.3. Best Management Practices on Golf Courses in Foreign Countries

For golf course building and optimized golf course operation and management, each US state implements its BMPs. To identify details of the golf course environment, particularly regarding pesticide usage, BMPs stipulated in 49 states except Mississippi were collected. Pesticide management and pest control on golf courses in Japan and Australia were also investigated.

3. Results and Discussion

3.1. Status of Korean Golf Courses

The number of golf courses in Korea increased from 2010 to 2019 (Figure 1a). In 2010, 396 golf courses were registered; this number exceeded 500 in 2014 and reached 539 in 2019, showing an increase of >36% compared with that in 2010. Of the 396 golf courses in 2010, 204 adopted a membership system, 156 adopted a public system, and 36 adopted other systems. Other systems primarily managed fitness training and have increased since 2015, albeit at a small scale. Although golf courses with a membership system accounted for 51.5% of the total registered golf courses in 2010, they decreased to 50% in 2013, <40% in 2018, and 36.5% in 2019, a decrease of 15% compared with that in 2010. With a decrease in the number of golf courses with a membership system, the number of golf courses with a public system increased from 39.4% in 2010 to 56.0% in 2019, an increment of 16.6%. Golf courses with a public system increased quantitatively as new golf courses opened to the public system and existing golf courses with a membership converted to the public system. The increase in the number of public golf courses could largely be ascribed to taxation and nontaxation aspects. The former aspect was related to saving tax by converting the membership golf course into a public golf course. The undeveloped area for environmental conservation was subject to separate aggregate taxation in public golf courses of Korea, so heavy taxation could be avoided. The latter aspect included the increase in the incomes of the public golf courses owing to the increasing number of users because public golf courses were easier to accommodate new golf players than membership golf courses [17,18]. In terms of the regional golf course distribution in 2019, Gyeonggi-do claimed the highest number of golf courses (162), accounting for >30% of the total golf courses (Figure 1b). This could be attributed to the dense population in the capital area, high demand for golf, and convenient location that enabled a natural environmental experience near downtown [19,20]. After Gyeonggi-do, the numbers of golf courses were the highest in Gyeongsang-do (53 and 42 in Gyeongbuk and Gyeongnam, respectively), Jeolla-do (26 and 43 in Jeonbuk and Jeonnam, respectively), Chungcheong-do (37 and 30 in Chungbuk and Chungnam, respectively), and Gangwon-do (64). Among the metropolitan cities, Busan and Seoul hosted the maximum and minimum numbers of golf courses, respectively (12 and 2, respectively). Moreover, the golf population in Korea was about 3.84 million in 2019, rending golf a sport with the largest single-sport population with a high growth rate. Consequently, there were challenges in predicting the demand for golf courses and the opportunities to play golf because of an imbalance between the supply of golf courses and the increasing demand of the golf players, seasonal changes, and requests for improved quality-of-service workforces. These factors should be considered for the future advancement of the golf industry and local economy [20,21].

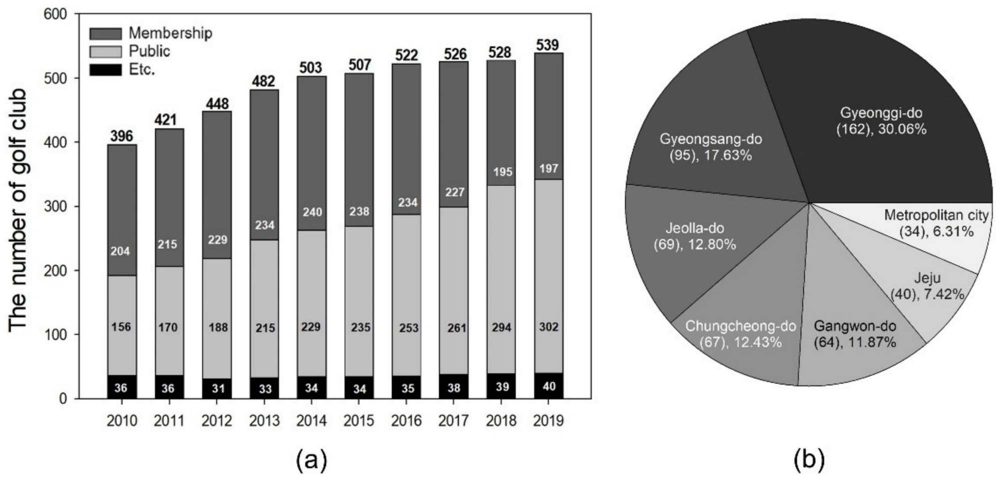

Figure 1. Distribution of the number of domestic golf courses. (**a**) Classification of golf courses by operational services from 2010 to 2019; membership golf courses (204 to 197), public golf courses (156 to 302), etc. (36 to 40) and (**b**) regional distribution; the number of golf courses is decreased in order of Gyeonggi-do (162, 30.06%), Gyeondsang-do (95, 17.63%), Jeolla-do (69, 12.80%), Chuncheong-do (67, 12.43%), Gangwon-do (64, 11.87%), Jeju (40, 7.42%), and Metropolitan city (34, 6.31%).

3.2. Status of Pesticide Usage on Golf Courses

As the number of golf courses increased, the overall area of golf courses in Korea also increased (Figure 2). The total golf course area was 35,900 ha in 2010 and increased to 51,700 ha in 2019, an increment of >44% in a decade. Pesticide-sprayed areas increased from 22,500 ha in 2010 to 31,400 ha in 2019, showing an increase of >39.5% in 10 years. The pesticide-sprayed areas include the teeing ground, green, fairway, rough, established green spaces, and practice putting green, whereas the unsprayed areas include bunkers, detention ponds, distributed reservoirs, roads for cart driving, teehouses, clubhouses, parking lots, and undeveloped areas for environmental conservation [22,23]. As areas of golf courses and pesticide usage increased because of the increasing number of golf courses (Figure 1a), the quantity of pesticide usage (based on the number of components) showed an upward trend (Figure 2). The total quantity of pesticides used (active ingredient) on golf courses increased from 115.8 tons in 2010 to 186.1 tons in 2019, an increment of >60%. This value decreased slightly in 2015 and 2017, likely because of complex influences from natural environmental factors (such as precipitation) and socioeconomic factors (such as efforts to decrease pesticide usage). Because diseases and insect pests in turfgrass and trees in golf course areas were highly related to humidity, precipitation considerably affected the quantity of pesticides used [24]. According to the data obtained from the Korea Meteorological Administration (https://www.weather.go.kr, accessed on 22 December 2021), precipitation values in summer and autumn in 2014 and 2016 were 892.9 and 827.8 mm, respectively, which reduced to 634.8 and 782.2 mm in 2015 and 2017, respectively. Thus, the quantity of pesticide usage decreased accordingly. Moreover, the use of pesticides was expected to decrease, owing to the 2015 agreement between Gyeonggi-do and some golf owners in Gyeonggi-do about using less pesticides. In some golf courses of Gyeonggi-do, pesticide consumption decreased by as much as 33% compared to the previous year [25].

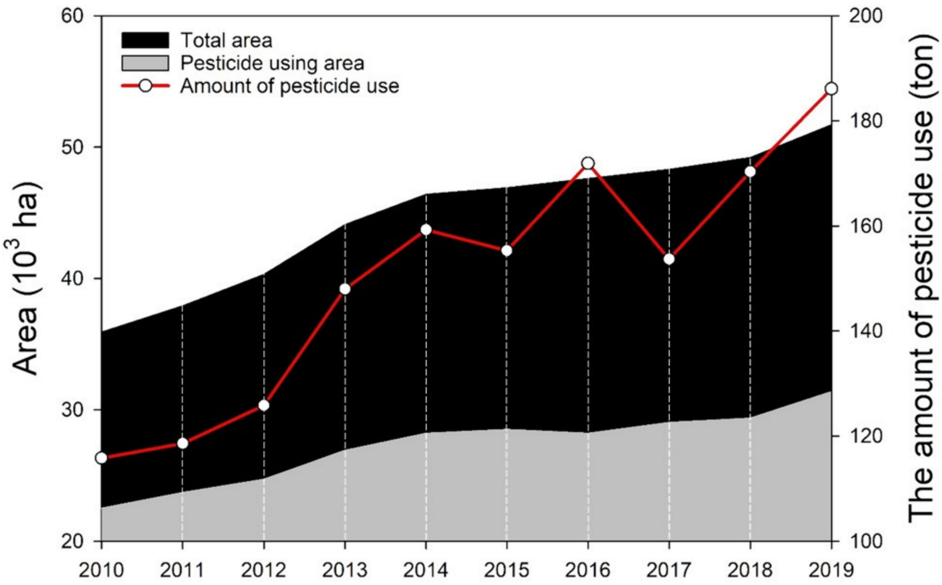

Figure 2. Area and quantity of pesticides used on golf courses in 2010–2019.

In Figure 3, chemical pesticides used in domestic golf courses are divided into five types according to their purpose. Based on the active ingredients, the most commonly used pesticides are fungicides, followed by insecticides, herbicides, growth regulators, and others. Fungicide usage indicated an overall increasing trend of 88, 105, 101, 112, and 125 tons in 2015–2019, respectively. Out of the total quantity of pesticides used, the proportion of fungicide usage increased in the order of 56.6% → 61.1% → 65.7% → 65.8% → 67.2% in 2015–2019, respectively. Recently, the use of insecticides has decreased (35, 36, 27, 32, and 31 tons in 2015–2019, respectively), and herbicide usage has showed a slightly changing trend (24, 25, 26, 22, and 24 tons in 2015–2019, respectively). More than half the pesticides used on golf courses comprise fungicides, and their proportion is increasing; moreover, fungicides and insecticides account for most of them. Of the 439 pesticides registered as crop-protecting agents for managing turfgrass in 2019, fungicides and insecticides were 300 and 44, respectively [1]. Diseases mainly found in Korean turfgrass include fairy ring, anthrax, large patch, dollar spot, pytium blight, blast disease, gray snow blight, and spring blight. The main pests found on grass are the larva of the black chestnut moth and grass chestnut moth, the back beetle, the alder beetle, the grass beetle, and the grass weevil [26]. In particular, although Korean-type turfgrass widely used in Korea has low fertilizer requirements and excellent disease tolerance, it is vulnerable to brown patch (large patch); thus, relevant fungicides are used in large quantities [22]. Scarab beetles and moths are the main target groups for insecticides used on golf courses, and crabgrass, annual bluegrass, and clover are the main target weeds for herbicides [27,28]. Recently, the development and introduction of ecofriendly pest control technologies were extensively studied for inhibiting new outbreaks and resistant bacteria, including the development of a new turfgrass species to control diseases and insect pests instead of resorting to the indiscriminate use of pesticides [29].

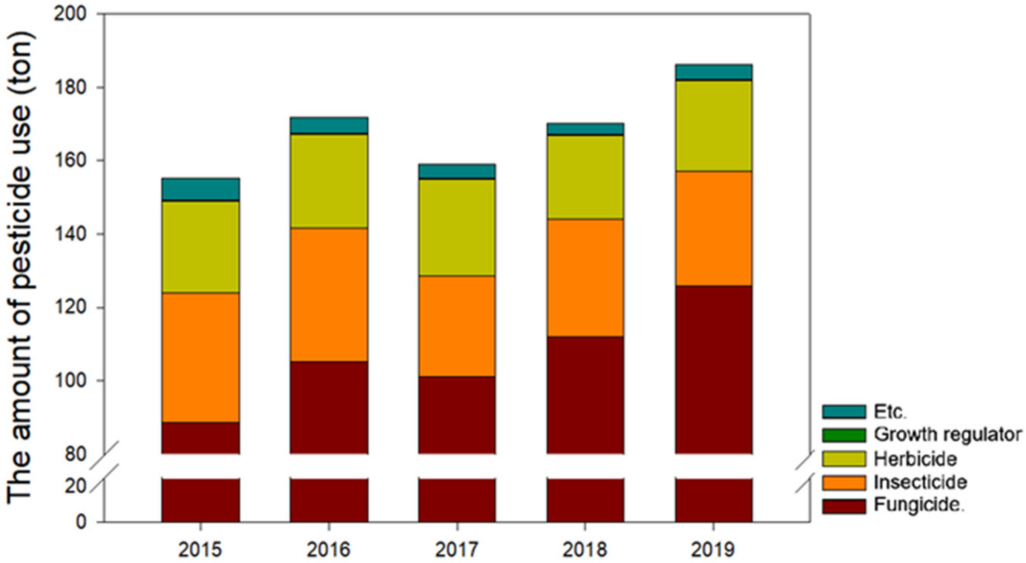

Figure 3. Quantity of pesticides used based on their types in 2015–2019.

3.3. Quantity of Pesticides Used Per Unit Area on Golf Courses

The quantities of pesticides used (active ingredient) per area (kg ha^{-1}) were distributed on the map using QGIS, which were based on the area actually sprayed with pesticides among the total golf course area in 2019 (Figure 4). The densely populated capital area showed concentrated golf courses, and golf courses belonging to the last class of pesticide usage per unit area of 12.77–65.82 kg ha^{-1} could be easily observed. Other than the capital area, golf courses were spatially distributed around metropolitan and large cities. Moreover, a small proportion of golf courses was distributed around the ecological network of Baekdudaegan, centered on the Taebaek Mountains. Unlike the west coast, golf courses were readily located along the seashore in the east and south coasts. In Jeju Island, 40 golf courses were located along the east–west division around the Halla Mountain, and 16 of 20 golf courses employing the maximum quantity of pesticides were distributed in the west, which are indicated by dark-red circles in the west on the map (Figure 4). The largest quantity of pesticide used in a golf course was 30.34 kg ha^{-1}, and there was one golf course that used no chemical pesticides in the eastside. Moon et al. [30] identified the distributions of soil orders and great groups and relations with the temperature, precipitation, surface geology, altitude above the sea level, gradient, slope aspect, distance to the seashore, and other environmental factors of Jeju Island, constructing a soil map with soil order and great group. Because of its geographical features, Jeju Island shows varied climate characteristics based on the bearing and altitude. The topographical effects of the Halla Mountain (1947 m high) and the influences of seasonal winds and humid environment impact the local life in Jeju Island; this is called wind culture [31,32]. To sum up, the soil properties, locations of large resorts, and climate characteristics during summer and winter in Jeju Island may have influenced the quantitative differences of pesticides used on golf courses in the east and west regions. This should be used as the primary research subject to help identify the effects of pesticide usages by soil environment and climate in Jeju Island.

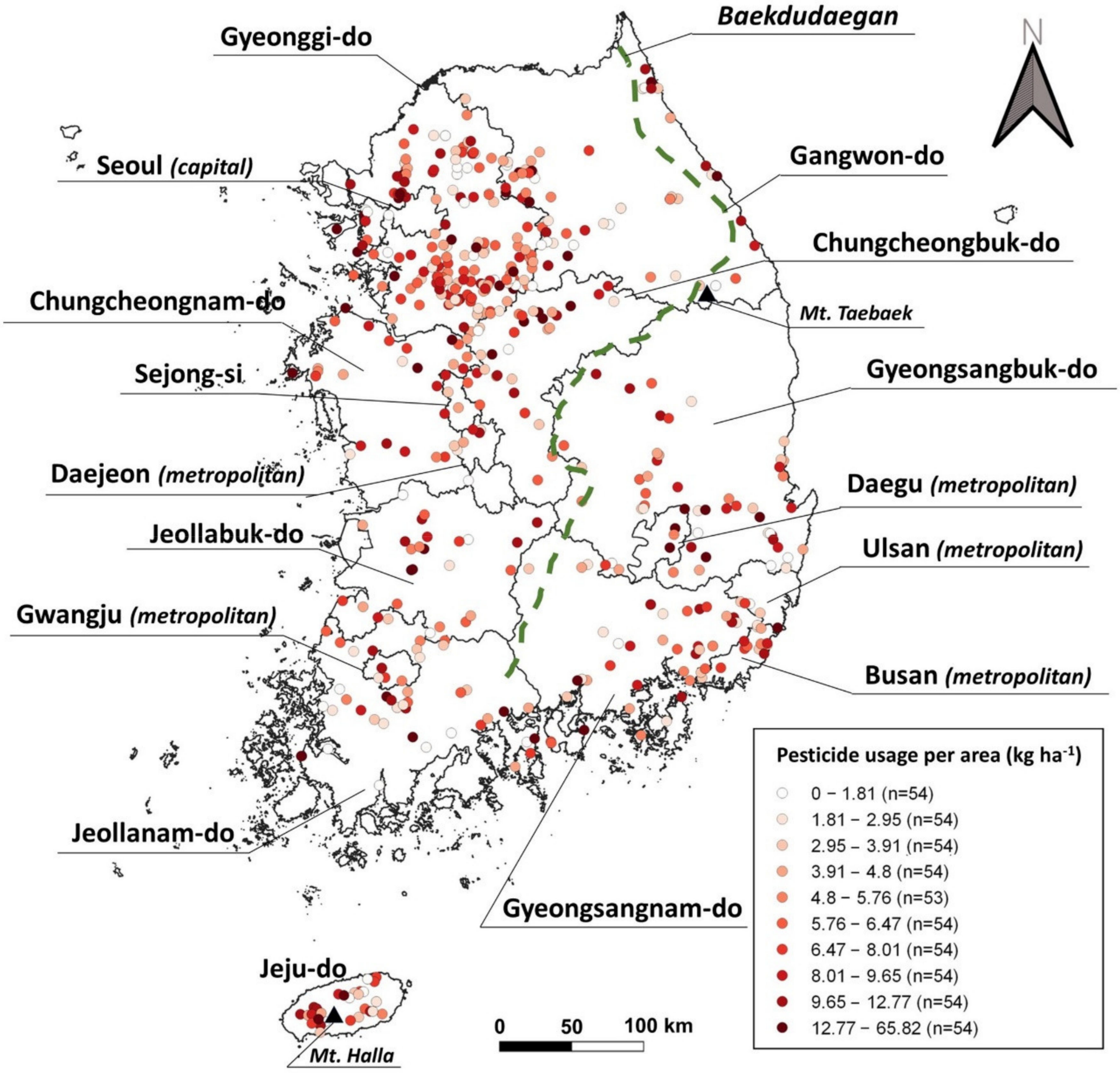

Figure 4. Spatial distribution and quantity of pesticide usage per area (kg ha^{-1}) of golf courses in the Republic of Korea in 2019 (n = 539).

Except for golf courses that opened or closed in the latter half of the year (June–December), five golf courses in Korea showed no pesticide usage, which were located in Gangwon (1), Gyeongnam (1), Jeju (1), and Jeonnam (2) in 2019. Moreover, of five golf courses employing the maximum quantity of pesticides per unit area, three were located in Jeonnam and one in Chungbuk and Gangwon each. The maximum quantity of pesticide usage per unit area was 65.82 kg ha^{-1}, and the pesticide usages per unit area in the 1st–3rd quartiles were 3.38, 5.77, and 8.78 kg ha^{-1}, respectively. The mean quantity of pesticide usage per unit area in the 539 golf courses was 6.97 kg ha^{-1}, and the total quantity of pesticides sprayed per area nationwide was 5.93 kg ha^{-1}, indicating a difference of 1.04 kg ha^{-1} with the mean of golf courses. Although the maximum quantity of pesticide usage per unit area on golf courses was 30.8 kg ha^{-1} in 2010, this value doubled or more in 2019. Golf courses that used pesticides per unit area of 10 kg ha^{-1} or more were <10% in 2010; however, this value increased to 18% or more in 2019, indicating an overall increase in the quantity of pesticides used on golf courses [22]. Pesticides were commonly used for food shortages during the Anthropocene owing to the groundbreaking increase in agricultural outputs [33]. A total of 16,700 tons of pesticides was used in farmlands in Korea in 2019, which is about 90 times greater than the pesticide usage on golf courses. The quantity of pesticides used per unit area of farmland was 10.2 kg ha^{-1}, which is about

1.5 times the quantity of pesticides used per unit area of farmlands compared to the quantity used on golf courses [34]. Therefore, despite the golf courses using fewer pesticides than the farmlands, the total quantity of pesticide usage and the quantity of pesticides used per unit area increased. In this regard, to encourage voluntary efforts from golf courses along with environmental regulations, the Han River Basin Environmental Office selected green management golf courses in 2011 and 2012, and the Ministry of Environment enforced and notified an Ecofriendly Golf Course Recognition Plan (EGRP) in 2012 [14]. According to the EGRP, when criteria were set for the assessment of the ecofriendly golf courses, a bonus point was added if the pesticides were used at a level of 2.5 kg ha^{-1} or less, which was in the lower 10% of pesticides use per unit area in 2010 [13]. If the criteria adopted in 2012 were to be applied in 2019, golf courses in the bottom 10% for pesticide usage achieved 1.97 kg ha^{-1} and 14% of the total golf courses used pesticides of 2.5 kg ha^{-1} or less. Therefore, while the number of golf courses increased by 143 from 2010 to 2019, the quantity of pesticide usage varied for each golf course, owing to the influences of the executive management's tendencies, course manager's turfgrass management practice, regional location, climate and soil characteristics [22].

3.4. Optimal Management Plan for Pesticide Usage on Golf Courses

As the number of golf courses increased, the gameplay area increased, consequently increasing the number of pesticide-sprayed areas and the quantity of pesticide usage (Figure 5a). In 2019, the minimum and maximum numbers of holes in golf courses registered in Korea were 3 and 81, respectively. Most golf courses (229) consisted of 18 holes, while 147, 114, and 26 golf courses were composed of 9, 27, and 36 holes, respectively. Although the relationship between the pesticide usage area and the quantity of pesticide usage per unit area was not clear, the latter decreased slightly in the exponential function as the area increased (Figure 5b). Larsen and Noack [35] reported that because farmworkers tended to routinely spray pesticides on agricultural land and did not make ecological decisions on pest management for farmlands, the quantity of pesticide usage per unit area increased. However, as pesticide spraying on turfgrass and trees at golf courses was performed based on the results of regular monitoring by course managers and hole staffs, it showed a different trend from the pesticide usage on farmlands [36]. According to Yoo et al. [3], the profits of golf courses increase considerably when the number of visitors per golf course hole increases. Chung and Yoon [17] compared golf courses adopting membership and public systems, reporting that an increase in the number of visitors increases profits. Finally, golf courses with fewer holes showed an increased number of visitors per hole, causing stress on turfgrass; accordingly, the quantity of pesticide usage per unit area increased to maintain the condition of turfgrasses. Furthermore, because the course and turfgrass management methods were different for each golf course, additional data and further studies were needed to identify the accurate cause of high pesticide use per unit area of a golf courses with few holes.

Hoy [37] explained the conventional process of pesticide usage for pest control in farmlands and golf courses as well as the tolerance of pests to pesticides in four phases using the adaptive loop cycle from a resilience viewpoint (Figure 6). In the front-loop exploitation phase, new chemical pesticides for effective pest control are developed, commercialized, sold, and used extensively (r denotes the increment rate) because they are widely employed, owing to their effectiveness. In the conservation phase, pests are not controlled appropriately because chemical pesticides reach the saturation or balance level, and instead, farmlands or golf courses are infested by pests (K denotes capacity). In the back-loop release phase, pests show resistance to existing chemical pesticides and become dominant, damaging the farmlands and the turfgrass of golf course, causing economic loss (Ω denotes termination). In the reorganization phase, novel chemical pesticides are developed for pest control, and with the possibility of pioneering the market (α denotes beginning), the cycle can once again enter the front-loop exploitation phase. Jeon and Lee [38] critically reviewed the aforementioned classic adaptive cycle and proposed an extended adaptive cycle by showing that resources might be consumed completely or become extinct by escaping the system, especially in the back-loop release phase. Clusters that have gone through a decline could be restricted, but in some cases, restructuring would fail (deviating from the adaptive cycle) because the growth engine may not become fulfilled in the reorganization phase [39]. When such an adaptive cycle continues, pest resistance and pesticide usage increase continuously, which may aggravate the burden on the environment.

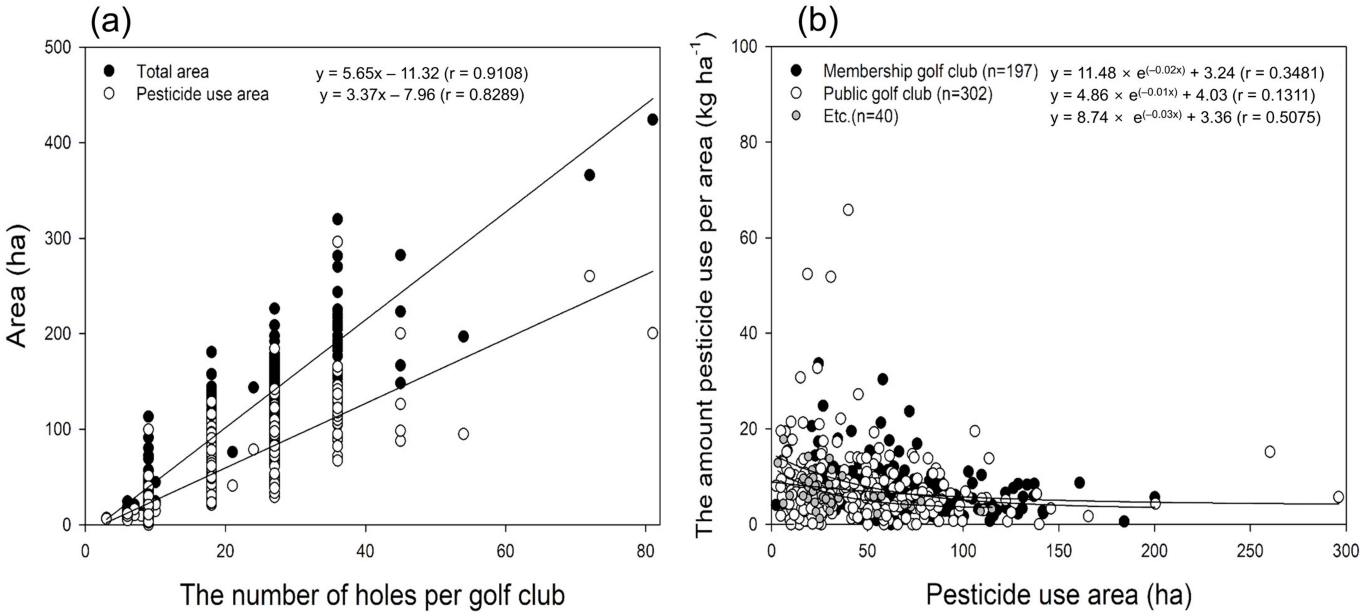

Figure 5. Relation between the golf course area and pesticide usage. (**a**) Number of holes per golf club vs. area of golf course; (**b**) pesticide use area vs. amount of pesticide use per area. Significance level of ANOVA for regression analysis was below 0.001 in (**a**,**b**).

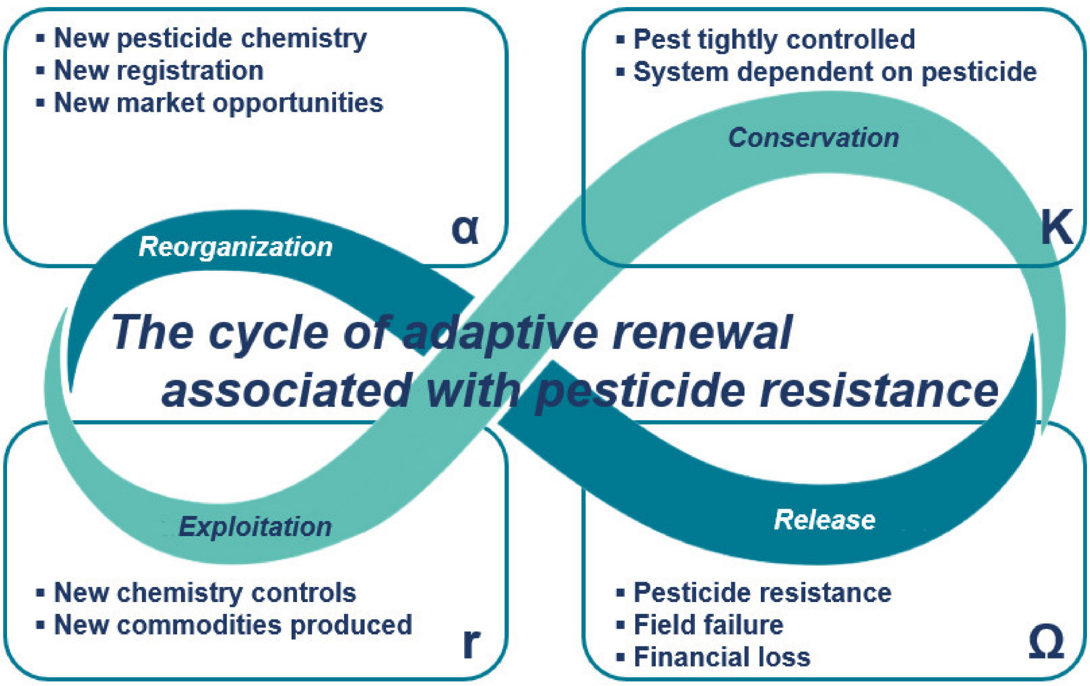

Figure 6. Four phases of the adaptive cycle comprising front (exploitation and conservation) and back loops (release and reorganization); adapted from Hoy [37].

The Chiba prefecture established a 'Regulation of Golf Course Development Plans in Chiba' in 1994, which prohibits the use of any chemicals to control weeds and pests on golf courses constructed after 1994 [40,41]. It also regulates the amounts of pesticides that can be used on golf courses built before 1994. Kato [42] reported that in Japan, physical and biological approaches are in the process of reducing pesticide usage and establishing comprehensive turf management in golf course. New South Wales in Australia introduced IPM with the key concept of introducing all the available methods to minimize pesticide use and keep pests at acceptable levels [43]. In the US, each state manages golf courses by stipulating BMPs for golf courses to minimize the quantity of pesticides used. To primarily examine the BMPs stipulated in states with the maximum number of golf courses (Florida: ~1100; California: ~920; and Texas: ~910), they could be classified into 13 sectors (water quality management, nutrition management, cultural practice, integrated pest management (IPM), pesticide management, habitat protection, facility maintenance/management, landscape, energy, local community participation, plan/design/construction, irrigation, and surface water management). The sectors related to the use of chemical substances including pesticides are the IPM and pesticide management [44–46]. IPM emphasized that the use of pesticides must be the last approach for pest control to minimize pesticide usage and proposed the idea of a threshold for final decision-making on pesticide usage (Figure 7). To provide an example with the figure, the ball on the left is the current golf course turfgrass system and shows the state where the commonly appearing dollar spot diseases began to partially emerge. For example, when the current turfgrass system is continuously affected by an external force or disturbance (e.g., highly humid soil because of intense rainfall and poor drainage), exceeds the threshold, and is converted into the new system on the right, dollar spot diseases become dominant, potentially reducing the turfgrass quality and causing economic loss. Therefore, the management of the turfgrass pest conditions of golf courses is essential to ensure that the system does not exceed the threshold, and the use of chemical pesticides should be the last approach when the condition involves the juncture of stepping over the threshold. Economic factors must be considered in addition to the distribution and the dominance of pest populations when calculating and setting the threshold [47,48].

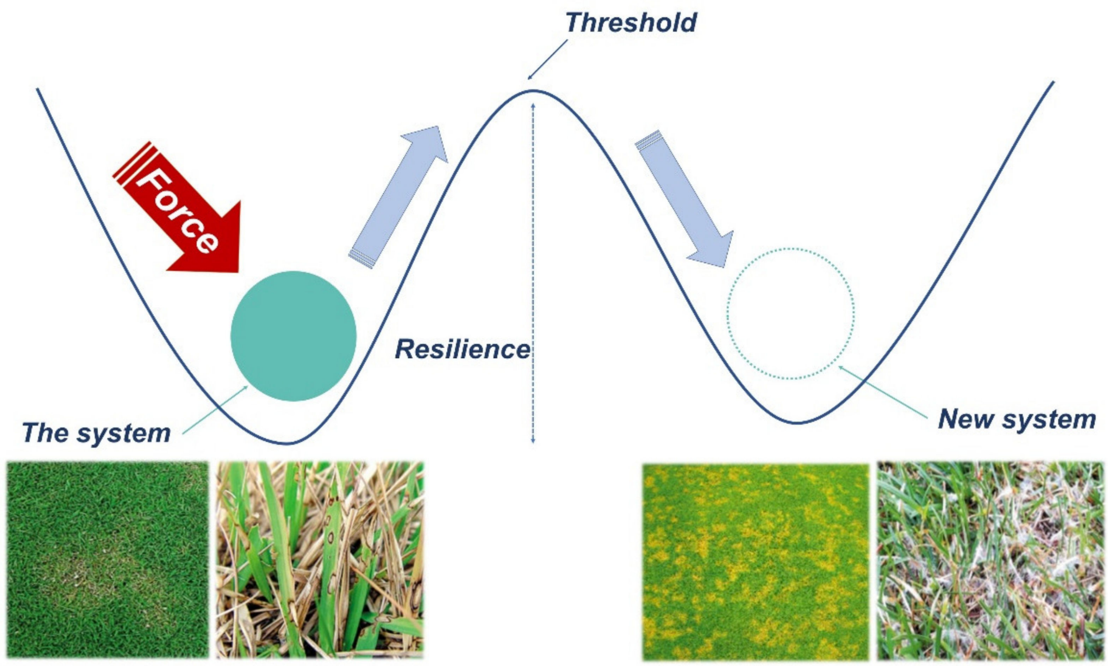

Figure 7. Example of regime shift of dollar spot (*Clarireedia homoeocarpa*) diseases from a resilience viewpoint. Images were obtained from the Korea Turfgrass Research Institute.

Continuous field monitoring should be performed to determine whether the pest outbreak condition has exceeded the threshold, and monitoring is the top priority and most critical phase in IPM [49]. A response pyramid for pest outbreaks could be shown based on the compilation of the IPM sectors in the US, BMPs and other research reports (Figure 8). Monitoring should be performed periodically in order to prevent pest outbreaks and turfgrasses, and trees should be observed for pest and disease continuously. When the pest outbreak condition reaches the next phase, action should be taken by cultural practices, such as mowing, cultivations, shade and tree management or sanitation management. When the pest outbreak progresses further, mechanical and physical methods should be adopted, including the removal of plants damaged by pests. The next response phase involves a biological method. Stenberg [48] presented the use of intrinsic heritable plant resistance, plant vaccination, interspecific and intraspecific botanical diversities, biorational synthetic volatiles, and biological control agents as examples. If the pest is not fully controlled despite adopting the aforementioned approaches, chemical management tactics for pest should be employed as the last measure.

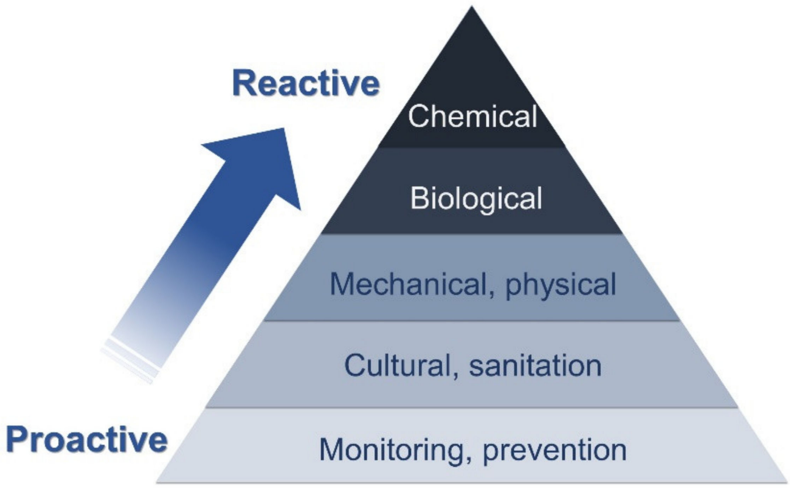

Figure 8. Pyramid of integrated pest management tactics.

It is not an overstatement to state that Korea was congested with golf courses relative to its territorial area and population because it globally ranked 8th in the number of golf club courses and 10th in the number of golf course facilities [50,51]. Despite this, no references or regulations for pesticide usage on golf courses were available, except the Guidelines on the Safe Use of Pesticides for Golf Course Turfgrass published by the National Institute of Environmental Research. Even in this case, the guideline was stipulated for workers handling pesticides and they fail to address pest control and the management of the quantity of pesticides used on golf courses. Although the present Korean laws prohibit the use of fatally or highly poisonous pesticides, it is necessary to minimize pesticide usage to the maximum possible extent to reduce the environmental pollution load and risks to human health. Hence, the establishment of IPM and BMPs for golf courses suitable for domestic conditions is essential.

4. Conclusions

Reduced pesticide usage on golf courses has become crucial considering the risks to human health and the environment associated with pesticide usage with the increasing popularity of golf. However, guidelines or manuals related to reducing pesticide consumption on golf courses in Korea are lacking. Hence, an optimal pesticide usage plan was proposed to continually decrease pesticide consumption in the future. As of 2019, Korea housed 539 golf course facilities, with a total golf course area of 51,700 ha and the quantity of pesticides used on golf courses of 186.1 tons. As the number of golf courses increased from 2010 to 2019, pesticide consumption also showed a steady upward tendency.

Fungicides accounted for more than half the pesticides used, followed by insecticides and herbicides. Except for golf courses that did not use any chemical pesticide, the pesticide usage per unit area varied from 0.02 to 65.81 kg ha^{-1} (an average of 6.97 kg ha^{-1}). In the US, each state stipulated and regulated BMPs and IPM to control pesticide consumption on golf courses, and these regulations inherently prescribed the use of chemical pesticides as the last approach for pest control and turf health management. Considering that Korea is globally within the top 10 countries in the number of golf facilities and courses, it is necessary to establish golf course pesticide management practices suitable for domestic conditions.

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