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Impact of Ultraviolet-B radiation based on altitude on photosynthetic efficiency, growth performance and crop yield: a review

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ABSTRACT

Purpose: Ultraviolet-B radiation was inducing enormous stress at highland and coldest area since it increases more than 40% at highland when we compare with lowland. Therefore, this review aims to assess and depict impacts of Ultraviolet-B radiation on photosynthetic efficiency, growth performance, and yield of crops based on altitude. **Findings:** Indicate that ultraviolet-b radiation has a severe effect on photosynthesis, especially the coldest time. It reduces photosynthetic efficiency in such an area, but it depends on the type of the crop and cultivar difference. On the other hand, it reduces growth performance and biomass accumulation based on altitude. There is a contrasting view on a net-assimilation rate on different studies condition. The effect of UV-B on crop yield was more contrasting in some studies says no effect on other studies it says it affect, but this contradictory result was mainly due to the difference in study conditions, still current studies on Yield revealed that UV-B has a high impact on yield. **Research limitations:** Ultraviolet-B radiation has high effect on the highland area, but there is no much research focuses, but UV-B was profoundly affecting photosynthetic efficiency, growth performance and yield of crops on highland area. **Directions for future research:** UV-B was reducing crop production, and productivity at highland and this review gives more insights on UV-B impact at the highland and allow UV-B adaptive and preventive investigation in the future.

INTRODUCTION

Chlorofluorocarbon and N_20 are causing depletion of the stratospheric ozone layer, which protects plants, animals, and humans from Ultraviolet radiation (Sharma, 2001). Starting from the last eighty years, Ultraviolet-B radiation reaching to the earth increases as a result of stratospheric ozone depletion by chlorofluorocarbon due to industrialization of the world (Sharma, 2001). Ultraviolet radiation was part of the non-ionizing region of the electromagnetic spectrum and account 5 up to 9% of solar radiation (Hollosy, 2002). It generally categorized into three wavelength ranges: Ultraviolet-C (100–280 nm) is particularly detrimental to living things, but not reach to the earth surface due to blockage by stratospheric ozone layers; Ultraviolet-B (280–315 nm) partially absorbed by stratospheric ozone layer and the most harmful that affect living things but Ultraviolet-A (315–400 nm) are the only harmless part of Ultraviolet radiation (Hollosy, 2002). Ultraviolet-B was particularly affecting the productivity of herbaceous dicot crop plants because 18-41% of it penetrates the mesophyll cell of this plant (He et al., 1994). Meanwhile, strength mostly depends on the altitude of the location since based on altitude there is a difference in thickness of the stratospheric ozone layer (Helsper et al., 2003; Bjorn, 1996). According to (Pfeifer et al., 2006), as elevation increase, Ultraviolet-B may increase more than 40% at high elevation area and this difference is mainly due to change in seasonal ozone depletion at highland. The increase or decrease of the Ultraviolet-B effect on plants also depends on the altitude, strength, duration of exposure, time of the day, angle of the sun, and the plant species (McKenzie et al., 2003). Ultraviolet-B has harmful effects on the morphology of crop plants mainly the increase of thicker leaves, reduction of petioles length, increase leaf curling, and change in leaf shape; diminish stem elongation, increased auxiliary branching and altered root: shoot ratio depending on the altitude (Robson et al., 2014). Similarly, if the UV-B dosage exceeds the limits of tolerance, plant anatomy will be changed, and biomass is decreased (Coleman & Day, 2004; Kakani et al., 2003; Zhao et al., 2004). Biomass accumulation, the partition of assimilating, leaf area and plant height significantly reduced when plants are exposed to ambient and enhanced UV-B radiation (Zhao et al., 2004; Gao et al., 2003). On metabolism, UV-B reduces photosynthesis, decreased proteins, impair chloroplast function, and decrease the relative growth rate, and damage DNA (Agrawal, 1992). Correspondingly, leaf area and plant height drastically reduced when plants are exposed to ambient UV-B radiation for a long time (Zhao et al., 2004; Gao et al., 2003). UV-B also enhances protective response in plants such as the biosynthesis of flavonoids and anthocyanin components (Jansen, 2002; Jansen & Bornman, 2012; Robson et al., 2014). These flavonoids and anthocyanin prevent the transmittance of the UV-B to the plant cells, thus the exclusion of UV-B damage to the plant molecules (Jansen, 2002; Jenkins, 2014). Therefore, this review aims to assess, and depict the impact of Ultraviolet-B on photosynthesis, growth performance, and yield of crops on different altitudes.

UV-B radiation difference based on altitude and latitude

The first research on ultraviolet light as a wavelength was carried out in 1800 by Ritter (Berg, 2008). UV radiation on the earth's atmosphere was first well-known in 1881 by Hartley, when he was able to measure ultraviolet energy hitting the land surface and found it different depending on altitude. Now, regions on earth between 40°N and 40°S latitude receive 2-11 kJ m-2 d^{-1} of UV radiation and the potential to increase in the future due to more significant ozone loss (Taalas et al., 2000; Rowland, 2006). As shown in Figure 1, Exposure to UV-B along different lines of latitudes vary due to ozone depletion, increases of ozone depleted by 40% in the Antarctic in contrast negligible increases occurred in the mid-latitudes since the

1970s (McKenzie et al., 2003). Higher altitude were having higher levels of UV-B due to a thinner atmosphere, closeness of the sun to the earth's surface, solar angle, and low albedo (Caldwell et al., 1980). This finding was in agreement with (Pfeifer et al., 2006), which reported that UV-B irradiance could increase more than 40% at a high elevation; this variation is due to change in the level of ozone depletion with altitude change as a result of regional aerosol conditions, solar elevation and also low albedo.

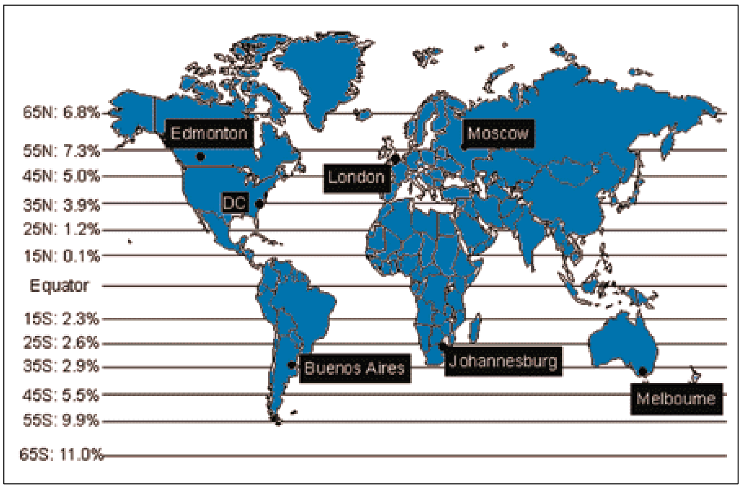

Fig. 1. UV-B trends of average annual increment and its strength based on latitude and altitudes (Lidon et al., 2012).

Ozone layer and Ultraviolet-B Radiation

Without the stratospheric ozone layer, a lot of UV-B radiation from the sun would not be blocked, reaching the earth's surface and causing incalculable damage to most living species. However, it is formed in the stratosphere when UV radiation from the sun strikes molecules of oxygen and causes the two oxygen bit to split apart, Freed atom bumps electrons into another O_2 it joins up forming ozone (O_3) this process is known as photolysis (Morrisette, 1989). Ozone measurement unit is the Dobson Unit, and it measures how thick the layer of the ozone when it is compacted into one layer at 0 degrees Celsius and with a pressure of one atmosphere above it, every 0.01 millimeter thickness of the layer is equal to one Dobson Unit (Margitan, 1991). Ozone concentration in the stratosphere across the globe is 300 DU or (a thickness of only 3mm at 0°C, and 1 atmospheric pressure). The ozone layer in the stratosphere filters UV-B wavelength from the earth's surface selectively (Rowland, 2006; Sarkar, 2011). However, currently, exposure to UV-B was increasing mainly due to depletion of the stratospheric ozone layer because of the high release of chlorofluorocarbon into the atmosphere and the breakage of the (O_3) atoms by chlorine (Rowland, 2006). The incidence of UV radiation varies by season with wintertime it increases as high as 35% per year while there is a 7% increase in summer due to greater ozone loss in colder temperatures catalyzing chlorine depletion of the gas (Kerr & McElroy, 1993). The same finding was reported by (Godin et al., 2001), stated that the stratospheric ozone trends in mid-latitude regions (25°-60°) show that ozone abundance over recent years was ≈ 4% below its 1979 values. The winter/spring and summer/autumn losses were of the order of 5.5% and 2.8%, respectively. According to studies at the middle of October, the highest UV-B symptom on plants grown at highland was seen, and this indicates stratospheric ozone depletion, UV-B, and cold temperature may have high correlation on its effect on photosynthesis, growth performance and yield of crops at the highland areas as showed in Figure 2. Similar findings were reported by (Wuebbles et al., 1998) Ozone concentrations clearly drop in the southern spring (September to October), recovering their normal values in November, although this recovery has been progressively delayed in recent times.

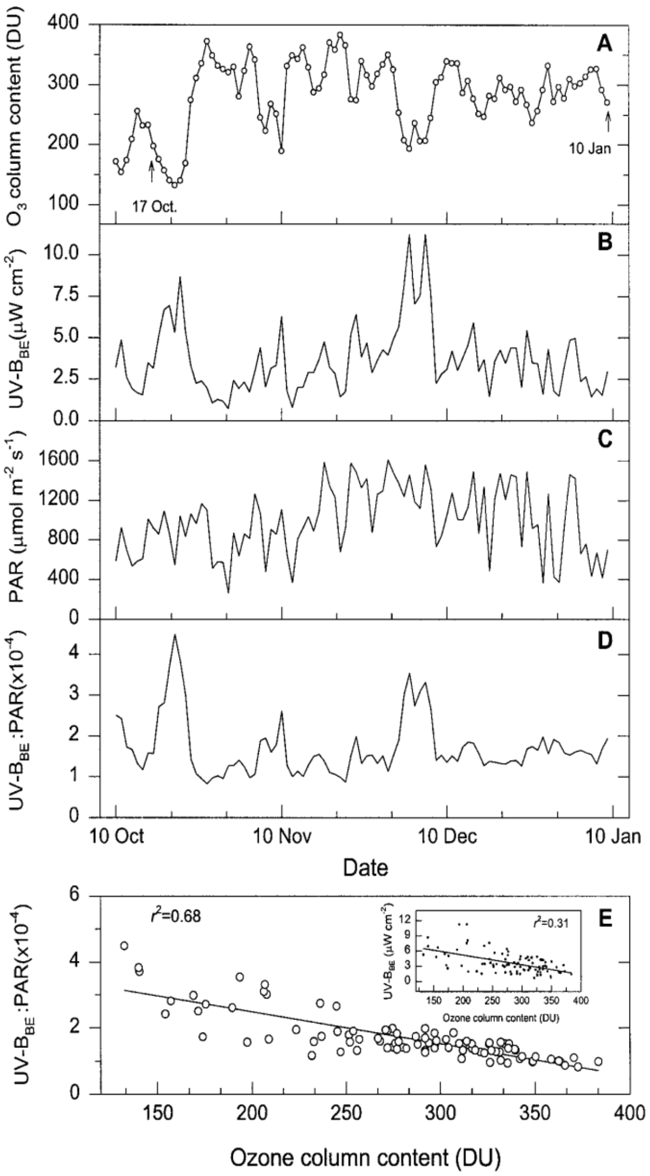

Fig. 2. Trends in total ozone column content (A), mid-day biologically effective UV-B (UV- B_{BE}; (B), mid-day PAR (C), and mid-day ratio of UV-B_{BE}-to PAR (D) at Palmer Station, Antarctica during the experiment. pointes indicate when plants were placed under UV-B treatments (October17,1998) and when they were harvested at the end of the experiment (January10, 1999). Ozone column content was measured with the National Aeronautical and Space Administration Total Ozone Mapping Spectrometer. Mid- day UV-B $_{BE}$ was taken as the mean of five measurements made at 15-min intervals between 12 noon and 1:15 PM by the SUV-100 spectroradiometer at Palmer Station that is part of the U.S. National Science Foundation's Polar UV Monitoring Network. PAR was measured with quantum sensors. The mid-day ratio of UV-B_{BE}-to-PAR was calculated in unit so Radiant flux density (e.g.m Wcm^{22}), after converting PAR data from units of photon flux density to radiant flux density by assuming an average wavelength of 550 nm. There were negative correlations between ozone column content and UV-B_{BE}-to- PAR (E) and UV-$B_{BE.}$ Source: (Xiong & Day, 2001).

Impact of UV-B on photosynthetic efficiency of crops

The reduction of the stratospheric ozone has led to an increase in UV-B radiation in recent decades (Schrope, 2000), and this increasing UV-B radiation reduce photosynthetic efficiency by directly altering photosynthetic process (Reddy et al., 2003), water metabolism (Fuhrer & Booker, 2003), and partitioning the carbon from growth pools to secondary metabolic pathways (Bassman, 2004). However, mostly it can damage plant cell membrane structure (Tanyolac et al., 2007). Yet, UV-B has a severe effect on plant metabolism, and according to the chlorophyll fluorescence test at highland, 0.72 was recorded, and this indicates UV-B reduce photosynthesis efficiency (Nogues et al., 1998), as shown in Figure 3, Table 1 and 2. The increasing levels of UV-B radiation currently shown inhibition of photosynthesis in pea, (Reddy et al., 2003; Zhao et al., 2004) in cotton, and (Allen et al., 1998) in oilseed rape.(Yao et al., 2006) reported that ambient and enhanced UV-B affects photosynthetic pigments that may reduce photosynthesis. Similar findings were reported by (Kataria et al., 2013) decrease in biomass has been associated with reduced rate of photosynthesis due to the impact of ambient UV-B. However, this low photosynthetic efficiency depends on the type of crop, and cultivar differences. According to the same findings reported by (Briscoe & Chittka, 2001; Irani & Grotewold, 2005; Chalker-Scott, 1999; Gould, 2004) anthocyanin are primarily known for their bright red colors and in plants anthocyanin was synthesized in response to excessive UV-B condition. (Jansen, 2002; Jansen & Bornman, 2012; Jenkins, 2014; Robson et al., 2014) reported similar findings that stated UV-B protective response in plants such as the biosynthesis of flavonoids and anthocyanin components that synthesized as a response to UV-B. These flavonoids and anthocyanin prevent the transmittance of the UV-B in to the plant cells, thus the exclusion of UV-B damage to the plant molecules (Jansen, 2002; Jansen & Bornman, 2012; Jenkins, 2014; Robson et al., 2014). (Oren-Shamir & Levi-Nissim, 1997) reported that the increase in anthocyanin content in the leaf in response to the UV-B showed more favorable performance ratings due to color. Plants produce a wide range of flavonoids and related phenolic compounds which tend to accumulate in leaves of higher plants as response to UV radiation (Tevini & Teramura, 1989; Rozema et al., 1997). It has been suggested that plants developed UV-absorbing compounds to protect them from damage to DNA or physiological processes caused by UV radiation (Stapleton, 1992).

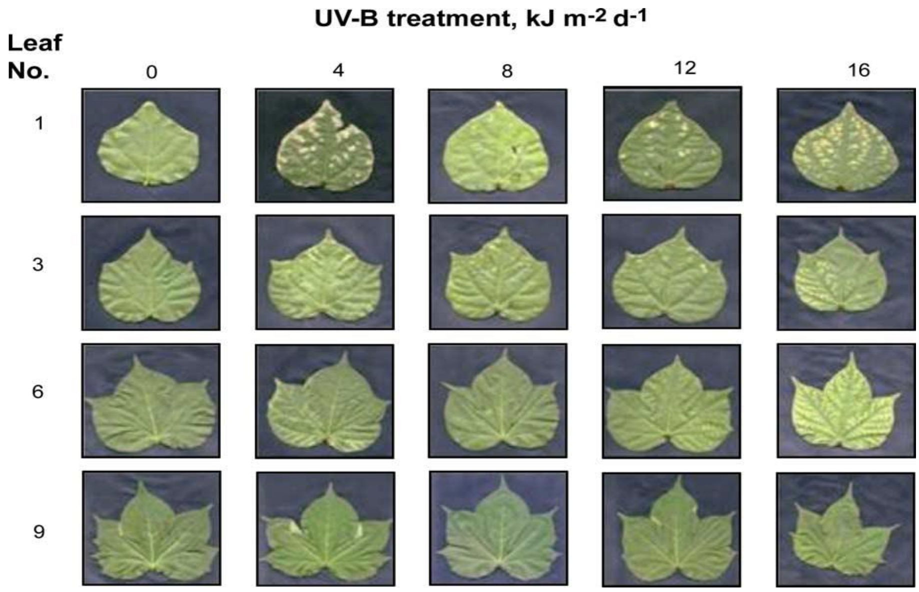

Fig. 3. Symptoms showing the damage caused by UV-B radiation on cotton leaves (Reddy et al., 2003).

These UV-absorbing compounds accumulate in the epidermis; preventing UV radiation from reaching the photosynthetic mesophyll cell (Stapleton, 1992; Braun and Tevini, 1993). (McKenzie et al., 2003; Caldwell et al., 1980) reported that higher elevations having higher levels of UV-B due to a thinner atmosphere, closeness of the sun to the earth surface, solar angle and low reflectivity. (Pfeifer et al., 2006) reported that UV-B irradiance increase more than 40% at highland area; this difference is due to change in the level of ozone depletion with elevation change and at highland area there is high seasonal ozone depletion and UV-B radiation.

Table 1. photosynthetic efficiency of sunflower plants grown without UV-B (-UV-B) and with UV-B (+UV-B) after 12 and 21 days of UV-B exposure

		Leaf 5		Leaf 13	
Sample	Variable	- UV-B	+UV-B	-UV-B	+UV-B
1st	*Ci*	174.29±13.03a[1]	152.43±17.85a	nd[2]	nd
	E	5.30±0.27a	3.81±0.20b	nd	nd
	gs	0.41±0.05a	0.20±0.02b	nd	nd
	A	26.87±0.21a	19.22±0.70b	nd	nd
	Fo	0.272±0.007a	0.292±0.005b	nd	N
	Fv	1.836±0.009a	1.818±0.020a	nd	dn
	Fv/Fm	0.868±0.001a	0.861±0.003a	nd	d
2nd	*CI*	257.83±9.41a	235.83±4.09a	208.50±8.14a	190.83±9.04a
	E	4.15±0.12a	3.68±0.28a	4.69±0.10a	4.25±0.19a
	gs	0.39±0.03a	0.29±0.05a	0.53±0.04a	0.37±0.04b
	A	13.63±1.15a	13.88±1.08a	23.70±0.67a	21.94±0.69a
	Fo	0.280±0.003a	0.282±0.005a	0.271±0.007a	0.263±0.003a
	Fv	1.830±0.017a	1.814±0.023a	1.839±0.016a	1.817±0.023a
	Fv/Fm	0.867±0.014a	0.865±0.024a	0.872±0.002a	0.874±0.001a

Source : (Cechin et al., 2007).

Table 2. Chlorophyll content (mg g^{-1}) of leaves of sunflower plants grown without UV-B (-) and with UV-B (+UV-B) after 12 and 21 days of UV-B exposure

		Leaf 5		Leaf 13	
Sample	Variable	- UV-B	+UV-B	- UV-B	+UV-B
1st	Chl*a*	1.81±0.01a[1]	1.61±0.07b	nd[2]	nd
	Chl*b*	0.58±0.01a	0.56±0.02a	nd	nd
	Chl*a*/*b*	3.09±0.03a	2.88±0.02b	nd	nd
	Chltotal	2.39±0.02a	2.16±0.09a	nd	nd
2nd	Chl*a*	1.75±0.12a	1.64±0.03a	2.27±0.14a	2.25±0.08a
	Chl*b*	0.69±0.05a	0.59±0.02a	0.78±0.03a	0.76±0.03a
	Chl*a*/*b*	2.57±0.18a	2.79±0.04a	2.91±0.10a	2.95±0.04a
	Chltotal	2.43±0.15a	2.23±0.05a	3.05±0.17a	3.01±0.11a

Source: (Cechin et al., 2007).

Impact of UV-B on growth and dry biomass accumulation of crops

The growth rate is a measure of how fast dry matter is stored in standing crops, and relative growth rate is an increase of dry mass per increment in time divided by existing biomass, but net-assimilation rate represents a plant's net photosynthetic effectiveness in capturing light; assimilating Co_2 and storing photoassimilates. According to Liu et al. (2013) report, UV-B radiation decreases the seed growth rate of three soybean cultivars on average by 12.5%, as shown in Table 3. The seed growth rate is shown to be a function of the cotyledon cell number, and the supply of assimilate to the developing cotyledons. (Egli et al., 1989), and (Feng et al., 2001) indicated that UV-B radiation reduces total biomass and yield per plant by 24.2% and 23.3% respectively. The same findings reported by (Kakani et al., 2003) state that exposure to UV-B radiation decrease the growth of leaves and stems in many plant species at both controlled environment and field studies, as shown in Figure 4. Zuk-Golaszewska et al. (2004) reported that high levels of UV-B decrease the relative growth rate by affecting nitrogen productivity, leaf area ratio, leaf area productivity, and leaf nitrogen productivity. However, Avery et al. (2004) reported that UV-B radiation often has an inhibitory effect on plant growth (up to 20%) in herbaceous species and, to a lesser extent, in woody perennials. studies done before state that partition of assimilating (net assimilation rate), and growth rate were reduce when plants exposed to enhanced UV-B radiation and this effect was due to its effect on photosynthesis and stomatal conductance (Zhao et al., 2004; Gao et al., 2003). However, contrasting result on net-assimilation rate was reported, prolonged exposure to UV-B light affect net assimilation, and relative growth rate in some rice cultivars (Dai et al., 1997), but high Ultraviolet-B radiation at highland area has no effect on net-assimilation rate this result was mainly due to light quality difference on different altitude, and the difference in cultivar and variety that alleviate the UV-B effect at ambient conditions. On the other hand, a decrease in biomass has been linked to a reduced rate of photosynthesis in many crop species by supplemental and ambient UV-B (Kataria et al., 2013). Other similar findings were reported which state that exclusion of UV-B from ambient level may lead to an increase in biomass production of various land plants and this indicates UV-B has severe effect on biomass production of various land plants (Mazza et al.,1999; Xiong & Day, 2001), and also there has been reported that the aboveground biomass may be reduced with exposure to UV-B radiation (Ballaré et al., 2001; Phoenix et al., 2002; Robson et al., 2003; Rozema et al., 2005).

Fig. 4. Effect of UV-B radiation on growth performance of Avena fatua (from the left 0, 4, 8 and 12 kJ/m2/d UV-B). Source: (Zuk-Golaszewska et al., 2004).

Table 3. Impact of UV-B on soybean yield and yield components

Cultivars	UV-B treatments	Yield per plant(g)	Pod number per plant	Seed number per plant	Seed number per pod	Seed size (mg)
H339	UV-B	12.3**	23.1**	48**	2.06	256**
	CK	20.2	32.8	70	2.12	289
HN35	UV-B	8.9**	26.5**	50**	1.89	175**
	CK	15.2	38.1	75	1.98	202
KN18	UV-B	7.7**	27.3**	58**	2.11	132**
	CK	15.6	48.3	104	2.16	150

Source: (Liu et al., 2013).

Impact of UV-B on crop yield

Many studies indicate that UV-B affects crop yield depending on the altitude at ambient condition and the types of the crop as well as the response of the cultivars. Reactions of various plants to UV-B radiation at both controlled environment and field studies; almost half of the studies showed that ambient, and enhanced UV-B radiation decrease yield, the other half showed no UV-B effect on yield (Kakani et al., 2003). Previous report indicate that UV-B reduces yield and the main reason for the reduction of crop yield with ultraviolet radiation is damage to organ membranes such as chloroplasts which make other stresses specifically, oxidative stress (Correia et al., 1999). These findings were in agreement with Yao et al. (2006) state that ambient and enhanced UV-B radiation probably affects photosynthesis and reduce economic yield. However, the contrasting result was reported by Hakala et al. (2002) who studied sensitivity of many plant species including barley, wheat, oat, clover, timothy, fescue and potato to UV-B radiation exposure (as if ozone layer decrease below 30%), and found no significant variation on biomass accumulation or yield of crop plants. However, recent experiments (Liu et al., 2009; 2013) indicated that UV-B radiation significantly decreases soybean yield per plant, as shown in Table 3. They showed that on soybean cultivars yield decrement was by 43.7%, and this yield reduction was mainly due to change in pod number per plant. Meantime, UV-B radiation decrease the seed size of three soybean cultivars by 12.3% (Liu et al., 2009; Chen et al., 2004) reported that the seed weight of the 15 soybean cultivars decreases quite significantly.

CONCLUSION

Based on the review, the following are concluded UV-B effect was more at the highland area, which revealed by research finding, physiological and visual observation of the UV-B symptom on plants mainly leaf curling. However, severity was high during at the season of low temperature or coldest time. This could be due to high ozone depletion at this time since at low temperature or coldest time the diffusion of gaseous molecules into the atmosphere was high, which could be mainly due to chlorine that depletes the ozone layer, and result in high UV-B incidence. This high UV-B has a severe effect on metabolism that result reduction of photosynthetic efficiency, biomass, growth performance and yield. Therefore, future research physiological, and molecular mechanisms of UV-B effect on plants must be studied. Natural and artificial UV-B exclusion mechanisms must be practiced at high altitude areas specifically, for dicot plants since they are the most sensitive, and further research must be needed to take UV-B adaptive and preventive measures.

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Conflict of interest
There is no conflict of interest on the manuscript.

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