Chapter 1

Introduction

1.1. Background

Air is one of the most important natural environments affecting living organisms. The influential Hipocrates already stressed the importance of good air quality in 400 BC. The presence of air pollution has been recorded as early as 150 BC and was part of everyday life for the inhabitants of cities like Athens and Rome. The emissions from homes, smelting furnaces, potteries and other pre-industrial workshops darkened the skies. This natural resource has since then been under immense pressure and the quality thereof threatened worldwide. In 1307 Edward I issued a royal proclamation to prohibit the use of coal due to the detrimental effect it had on inhabitants' bodily health (Mosley, 2012).

Pollutants affecting air quality today include particulate matter ($PM_{2.5}$ – PM_{10}), ozone (O_3), nitrous oxides (NO_x), carbon emissions and sulphur dioxide (SO_2) (Gurjar *et al.*, 2010; Molina & Gurjar, 2010). Air pollution may be produced by natural means when released into the atmosphere during volcanic activity, vegetation decay or forest fires. Most air pollutants are man-made and released during the combustion of fossil fuels (PM, SO_2 and NO_2), photochemical reactions involving the conversion of NO_x (a derivative of vehicle and industrial smog) and emitted by vehicles, solvents and industry as VOCs (volatile organic compounds) which is responsible for the formation of ground-level O_3 (Molina & Gurjar, 2010).

The regulation of emissions is largely beyond the control of individuals and requires action by governmental bodies, public authorities at national, regional and even international level (Gurjar *et al.*, 2010). An annual mean concentration of 11.5 ppb SO_2 is the European critical level or threshold at which a 5 % yield reduction can be expected for agricultural crops (Ashmore & Marshall, 1998). In South Africa, air pollution was first identified as a potential threat to vegetation in 1988 (Tyson *et al.*, 1988; Van Tienhoven & Scholes, 2003) which raised the urgency for regulation of emissions through revision and implementation of protocols. It is, however, problematic to adopt information regarding the effect of air pollution on plant species from the northern hemisphere because considerbly different environmental factors are involved.

The response of plants to air pollutants in hot, dry climates (such as in South Africa) may be influenced by water and temperature stress. Patterns of temperature-dependent plant responses to air pollutants seem quite different in different species and generalisations about the influence of exposure temperatures on resistance of plants to air pollutants are limited. Similarly, water stress may protect plants from air pollutants when the stomata close in response to water stress to reduce the loss of water by transpiration. If stomata are closed, the uptake of air pollutants decrease and subsequent damage to plants will decrease concomitantly (Schenone, 1993; Levitt, 1980). These examples suggest that species' dose-response to air pollutants developed elsewhere, should be applied with due care in South Africa, and that pollutant-dose response reseach done in developing countries are of immense value (Van Tienhoven & Scholes, 2003).

1.2. Hypotheses

Previous studies concluded that the biochemichal mechanisms of crop plants are strongly affected when exposed to air pollution. The effect of disrupted metabolic pathways is mostly reflected as foliar damage and a decline in growth and/or yield. The addition of drought as co-stress induces partial closure of the stomatal appertures which may ameliorate the adverse effect of the air pollutant. As photosystem II (PSII) is known to be sensitive to stress (Stirbet & Govindjee, 2011) it is hypothesised that SO_2 will adversely affect the functioning of PSII in *Brassica napus* and *Zea mays* and disrupt the metabolic pathways in such a way that a reduction in yield will occur. It is secondly postulated that with the addition of drought as co-stress, partial stomatal closure will occur in both *Zea mays* and *Brassica napus* crop plants thus mitigating the effect of SO_2 on the photosynthetic apparatus, growth and yield.

1.3. Aims

The aim of this study was **(i)** to quantify the impact of different SO_2 concentrations on the photosynthetic capacity of two crop plants, *Brassica napus* (C_3) and *Zea mays* (C_4), subjected to well watered (WW) (~80% of field capacity) and drought stress (DS) (~20% of field capacity) conditions; **(ii)** to study the ecophysiological and biochemical basis of SO_2 injury in the mentioned crop plants, with special emphasis on the primary processes of photosynthesis and photosynthetic gas exchange.

The following evaluations were carried out in parallel to assess plant response to SO_2 fumigation:

1. Leaf integrity, biomass and yield.
2. Chlorophyll content index (CCI) (*in vivo*).
3. *In vivo* photosynthetic gas exchange and the limitations on the gas exchange determining the relative contribution of mesophyll (biochemical) and stomatal limitation by analysing the CO_2 response curves.
4. *In vivo* Chlorophyll ***a*** fluorescence induction and quantification of the fluorescence transients according to the JIP-test (Strasser *et al.*, 2000; Strasser *et al.*, 2004; Yusuf *et al.*, 2010). To supply information about the response of primary photochemistry.
5. Activity of the antioxidant enzyme POD, using *in vitro* enzyme essays.
6. An important aspect of the study was to compare the response of the C_3 and the C_4 species to SO_2 and the interaction with drought.

1.4. Structure of the thesis

The thesis consists of seven chapters. Chapter 1 is an introductory chapter. Chapter 2 is a literature study covering the following aspects: (i) the origin of the air pollutant SO_2; (ii) how the South African highveld area (which is the major source of SO_2 generation in South Africa) is influenced by pollution; (iii) the effects of SO_2 on plants and its interaction with drought; (iv) how plants respond to stress conditions; (v) a discussion about two important crops in South Africa, i.e. the winter crop *Brassica napus* and the summer crop *Zea mays* and their specific modes of CO_2 fixation, namely C_3 metabolism and C_4 metabolism, respectively. Chapter 3 provides an overview of the methods and materials used to conduct experiments on *Brassica napus* and *Zea mays*. In Chapter four and five the data of the study are presented. Chapter 4 deals with the results and discussion obtained with the C_3 crop *Brassica napus* (Canola), while in Chapter 5 the data obtained with the C_4 crop, *Zea mays* (maize) are discussed. Chapter 6 comprises a detailed and recapitulatory discussion of the results and the conclusion. Here the visual effects of SO_2 on *B.napus* and *Zea mays,* the effect of SO_2 and its interaction with drought on photosythesis and crop yield is discussed. Recommendations and perspectives for future research are suggested. In Chapter seven a list of all the references is supplied.