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***Full Length Article***

# Effects of Ozone Stress on Absorption, Distribution and Utilization of Potassium in Rice under Different Planting Densities

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## Abstract

A conventional rice variety Yangdao 6 and a hybrid rice variety II You 084 were evaluated under Free Air gas Concentration Enrichment (FACE), in current ozone concentration and high ozone concentration to explore the effect of ozone stress on absorption, distribution and utilizing of potassium (K) under low, medium and high planting density in rice. Results showed that, compared with current $O_3$ concentration, high ozone concentration increased the K level in all rice organs, especially at heading stage and maturity stage and its concentration in Yangdao 6 was higher 10.4% ($P < 0.05$) at heading stage and 7.5% ($P < 0.05$) at maturity stage, and that of II you 084 was higher 9.1% ($P < 0.05$) and 8.0% ($P < 0.05$) separately at corresponding stages. High ozone concentration decreased the K accumulation in both of two cultivars at each growth period with decrease of 9.1% ($P < 0.05$) in Yangdao 6 at maturity stage, and of 9.8% ($P < 0.05$) at tillering stage, 8.3% ($P < 0.05$) at jointing stage, 8.0% ($P < 0.05$) at heading stage, and 19.7% ($P < 0.01$) at maturity in II you 084, but affected the K distribution in each rice organ irregularly. In conclusion, high ozone concentration had little effect on the K harvest index in rice, but decreased the K grain production efficiency with decrease of 5.8% ($P < 0.1$) in II You 084. These results indicate that high ozone concentration increases the level of K in rice plant, but decreases its accumulation and utilization significantly.


**Keywords:** Rice; Ozone; Density; Potassium

## Introduction

In many Asian countries, with the fast development of economic, air pollutants-nitrogen oxides and volatile organic compounds discharge are increasing, of which precursor transforms into ozone through photochemical reaction under high temperature and strong irradiation, rising troposphere ozone concentration, especially developing countries with large population density (Emberson *et al.*, 2001; Fowler *et al.*, 2008). According to prediction, the mean surface ozone concentration in Southeast Asia is going to be higher 25 nL/L in future 40 years than now (Fowler *et al.*, 2008). As a strong oxidant, at present, the surface ozone concentration is over the threshold value (40 nL/L) of ozone injury for the sensitive crops (Krupa *et al.*, 2001; León-Chan *et al.*, 2017), which has negative influence on the growth of crops including rice, and may affect more in future (Ainsworth, 2008; Feng and Kobayashi, 2009; Sun *et al.*, 2009; Ainsworth and Mcgrath, 2010; Wang and Frei, 2011).

Lal (2013) reported that the actual change of atmospheric environment including the raise of ozone concentration brings a set of direct and indirect global food safety problems, such as decline in land use, ecological environment change, decrease in water use efficiency and food production including poor quality. Extensive researches are performed for the response of rice growth and production under ozone stress by some people (Ainsworth, 2008; Yang *et al.*, 2008; Wang and Frei, 2011), of which most are single factor experiments, and few are multiple factor evaluating the effect of ozone and cultivation condition (Yang *et al.*, 2008). In terms of fumigation, most of the previous researches about rice ozone trials are implemented in air chamber (Yang *et al.*, 2008). However, narrow testing space in air chamber and artificial segregate installation leads to huge disturbances to microclimate around the plants, adding marginal effect of air chamber test, these disturbances may change the response range of crops to ozone stress. Compared with air chamber, FACE test is operated in open farmland, regarded as the best way to assess the actual effect of atmosphere constituent change on crops production (Long *et al.*, 2005).

Potassium (K) is well-known as one of the necessary nutrient elements of plants and the basic fertilizers maintaining high crops production, and as a participants of set of physiological and biochemical process inside plants,

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play an essential role in growth, metabolism, fermentation activity and permeation regulation (Pettigrew, 2008; Marschner, 2011). As the improvement of rice quality, the increase of yields, cropping index and phosphorus amounts, and the use of straw as fuel and livestock food, K deficiency of paddy soil is getting worse (Yadav, 1998; Wihardjaka *et al.*, 1999). Obviously, the absorption and use of K in rice under atmospheric environment with high ozone concentration in future play a major role in rice yields and quality. There are few previous researches about it (Welfare *et al*., 1996; Fangmeier *et al.*, 1997, 1999), with single experimental crops variety, making difficult to understand whether the K metabolism, distribution, and transport mechanism of various varieties response to ozone pollution are uniform.

As one of the essential food sources for human being, rice provides nutrient for more than half population worldwide (Irri *et al.*, 2002), hence, it is important to underpin the influence of ozone pollution on K metabolism in diverse rice breeds. This project, which relies on China's advanced ozone FACE to simulate the earth surface ozone concentration in the middle of this century, studies firstly the response difference of absorption, distribution, and use of K in various rice varieties under different density to high ozone concentration and its possible reasons with conventional rice Yangdao 6 and hybrid rice II you 084. The overall aim was to assess the effect of K on rice under ozone pollution and supply of potassic fertilizers.

## Materials and Methods

### Background of Experimental Field and Ozone FACE Platform

Relying on the China's $O_3$-FACE platform, this trial was carried out with rice-winter wheat rotation in the farm experimental field located at Xiaoji town, Jiangdu city, Jiangsu province, China (119°42'0″E, 32°35'5″N), where the annual precipitation is about 980 mm, average evaporation capacity of 1100 mm, mean temperature of 14.9℃, sunshine hours >2100, relative humidity of 87%, and average annual frostless period of 220 days. The soil type in this experimental field was clear earth, with physicochemical properties of 18.8 g/kg organic carbon, 1.58 g/kg total nitrogen (N), 0.67 g/kg of total phosphorus (P), 15.1 g/kg total K, 10.8 mg/kg available P, and 72.1 mg/kg of available K with bulk density of 1.23 g/cm$^3$ and 7.3 pH (Peng *et al.,* 2016). The experimental platform had four FACE experimental cycles shaped in regular octagon (14 m in diameter) and four control cycles in total, and the effective area of each cycle was approximate 120 m$^2$. In order to reduce the influence of ozone release on other cycles, the interval among the FACE cycles and the control cycles were greater than 70 m. The small hole on the tubes (located at 50~60 cm above the canopy of crops) around FACE cycle sprayed pure ozone toward the center. In order to maintain the ozone concentration in the central canopy of FACE cycle 50% higher than in atmosphere, the computer system detected such factors, including ozone concentration, wind direction and speed, to regulate automatically the release speed and direction of ozone based on concentration monitoring system in the cycle. Degassing started from July 1 till rice maturity, from 9:00 a.m. to 16:00 p.m. every day, but suspended when ozone concentration in the control cycle was lower than 20 nL/L, leafs moistened by rain and dew, ozone analysis device correction, and equipment overhaul. The actual mean ozone concentration in FACE cycle during the entire growing season of rice was higher approximately 23% (2011) and 27% (2012) than in the control cycle. Without equipping FACE tubes, the environmental condition of the control fields was in accordance with the natural condition (Tang *et al.,* 2011). Samplings of FACE cycle at each key growth stage and maturity were taken in effective region, located within 1.5 m of FACE spray tubes with more stable ozone concentration. The change of ozone concentration in the FACE cycle and the control cycle during ozone fumigation in 2011 and 2012 was given in Fig. 1.

*NOTE: C-$O_3$: Current $O_3$ concentration, E-$O_3$: Elevated $O_3$ concentration, The sames below*

### Tested Cultivars and Materials Cultivation

The cultivars were Yangdao 6 (during 2011) and II You 084 (during 2012), sown at May 22, transplanted at June 21, and the fertilizer application was 15 g/m$^2$ N, 7 g/m$^2$ P and K.

### Experimental Treatment

The experiment was conducted in split plot experiment, with ozone concentration in the main plot, varieties and transplanting density in the split plot, repeated each treatment three times. The transplanting densities were low (16 plants/m$^2$, planting spacing 25 cm), medium (24 plants/m$^2$, P × P 16.7 cm × 25 cm), and high (32 plants/m$^2$, P × P 12.5 cm × 25 cm).

### Determination of K

The K level and accumulation in the plant and its organs were measured at tillering, jointing, heading, and maturity stages. Six representative plants were selected in each plot, of which each organ dry sample was grinded and oven-dried (green removing for 30 min under 105℃, baked for 72 h under 80℃), and then digested by microwave (microwave digestion instrument, CEM/MARS). After digestion, the K level in each rice organ of these samples was tested and the K accumulation at each growth stage was counted by inductively coupled plasma-atomic emission spectrometry (ICP-AES, America).

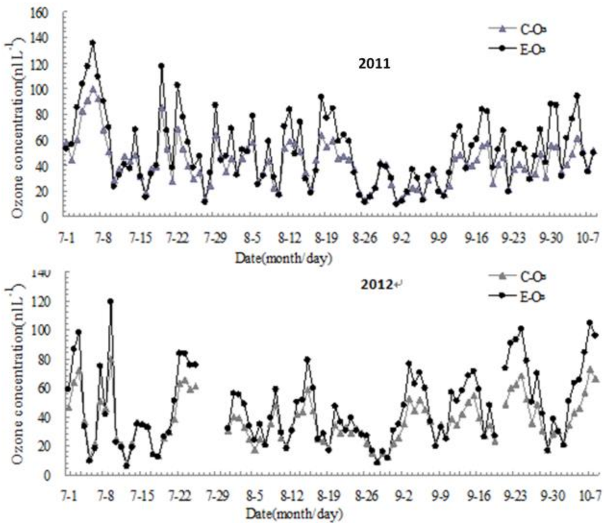


**Fig. 1:** The change of day time 7-h mean ozone concentration during ozone fumigation

The K use efficiency included three main indexes, such as K dry matter production efficiency, K grain production efficiency, and K harvest index, its correlation formula was as followed.

K dry matter production efficiency = the dry matter accumulation at each growth stage/the dry matter accumulation of the whole plant at corresponding growth stage (g $g^{-1}$)

K grain production efficiency = grain production/the K accumulation of the whole plant at maturity stage (g $g^{-1}$)

K harvest index = the K accumulation of grain/the K accumulation of the whole plant at maturity (%)

## Results

### K Absorption

*NOTE: LD means low density, MD means medium density, HD means high density, the sames*

The high ozone concentration had irregular effects on the K level in rice green leafs, but in stems, it increased at different growth stages (Table 1). The K concentration in cultivar Yangdao 6 increased by 8.0% ($P < 0.05$%) at tillering, 20.3% ($P < 0.01$) at heading, and 13.6% ($P < 0.05$) at maturity stage, and in II you 084 increased by 15.1% ($P < 0.05$), 8.6% ($P > 0.05$) and 11.9% ($P < 0.05$) respectively at corresponding stages (Table 1). Meanwhile, it also increased the K level in spike at middle and late stages, while Yangdao 6 ascended 34.8% ($P < 0.01$) at heading stage and 5.2% ($P < 0.1$) at maturity, and II you 084 increased 6.5% ($P < 0.1$) at maturity. In terms of the whole plant, the K level of rice increased at each growth stage by ozone stress, and for Yangdao 6 raised 34.8% ($P < 0.01$) at heading stage and 5.2% ($P < 0.1$) by maturity, and II you 084 increased 9.1% ($P < 0.05$) and 8.0% ($P < 0.05$) separately (Table 2). The variance analysis indicated that ozone stress had no effect on the K level of each organ and the whole plant at various growth stages under diverse densities.

The K accumulation in whole plant at each stage decreased by high ozone concentration, and for Yangdao 6, K concentration decreased a little at early and middle stages, but 9.1% ($P < 0.05$) at maturity stage, and for II you 084 reduced by 9.8% ($P < 0.05$) at tillering, 8.3% ($P < 0.05$) at jointing, 8.0% ($P < 0.05$) at heading, and 19.7% ($P < 0.01$) at maturity stages (Table 3). However, the interaction of ozone and variety showed large difference in the K accumulation in whole rice plant at maturity stage.

### K Distribution

High ozone concentration had irregular effects on the K distribution ratio in each rice organ at different growth stages. And in green leafs of Yangdao 6, it increased 17.4% ($P < 0.05$) at jointing, but decreased 13.2% ($P < 0.05$) at heading; and in stems declined by 14.8% ($P < 0.05$) at jointing stage. While of II you 084, K distribution also decreased by 6.5% ($P < 0.1$) at maturity; and in spike of Yangdao 6 and II you 084 increased 24.2% ($P < 0.05$) and decreased 11.6% ($P < 0.05$) separately at heading stages (Table 4). Variance analysis showed that the K distribution ratio in spike at the heading stage was influenced by the interaction of ozone and variety.

### K Use Efficiency

*NOTE: C means cultivar, D means density, TS means tillering stage, JS means jointing stage, HS means heading stage, MS means maturity stage, the sames* Fig. 2.

The K dry matter production efficiency of rice at each growth stage decreased by high ozone concentration (Fig. 2 and Table 5), and at the tillering and jointing stages declined a little. While for Yangdao 6, it lowered by 9.8% ($P < 0.05$) at heading and 4.6% ($P < 0.1$) at maturity and for II you 084, it decreased 9.2% ($P < 0.05$) at heading and 8.0% ($P < 0.05$) at maturity stages. The interaction of ozone, variety and density had little difference in the K dry matter production efficiency of rice at various stages.

The K grain production efficiency of rice showed decreasing trend due to high ozone concentration (Fig. 3 and Table 5), and for Yangdao 6 changed a little, but for II you 084 lowered by 5.8% ($P < 0.1$). The interaction of ozone, variety and density had no significant difference in the K grain production efficiency of rice.

High ozone concentration had little effect on the K harvest index of Yangdao 6 and II you 084 (Fig. 4 and Table 5), and the variance analysis also showed that interaction of ozone, variety and density had no significant difference in the K harvest index.

**Table 1:** Effects of surface ozone concentration and plant density on K concentration in the organs of rice under FACE condition

| C | D | $O_3$ t | Green leaf | | | Stem | | | | Spike | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | T stage (mg $g^{-1}$) | J stage (mg $g^{-1}$) | H stage (mg $g^{-1}$) | T stage (mg $g^{-1}$) | J stage (mg $g^{-1}$) | H stage (mg $g^{-1}$) | M stage (mg $g^{-1}$) | H stage (mg $g^{-1}$) | M stage (mg $g^{-1}$) |
| Y | LD | C-$O_3$ | 21.0 ± 0.7 | 16.1 ± 0.8 | 15.2 ± 0.3 | 31.3 ± 0.7 | 16.1 ± 1.0 | 12.8 ± 1.9 | 14.5 ± 0.7 | 7.8 ± 0.1 | 2.60 ± 0.05 |
| | | E-$O_3$ | 20.3 ± 0.4 | 18.4 ± 0.4 | 13.3 ± 0.7 | 31.0 ± 0.9 | 14.9 ± 1.1 | 13.4 ± 1.0 | 18.1 ± 1.1 | 10.1 ± 1.0 | 2.80 ± 0.08 |
| | MD | C-$O_3$ | 20.0 ± 0.7 | 16.0 ± 0.3 | 15.0 ± 0.6 | 26.6 ± 2.2 | 16.1 ± 1.2 | 11.6 ± 1.3 | 14.5 ± 0.5 | 7.4 ± 0.3 | 2.69 ± 0.04 |
| | | E-$O_3$ | 21.4 ± 1.7 | 18.7 ± 0.4 | 13.5 ± 0.6 | 33.0 ± 1.5 | 14.4 ± 0.4 | 13.2 ± 2.0 | 15.4 ± 0.6 | 9.3 ± 1.0 | 2.78 ± 0.02 |
| | HD | C-$O_3$ | 19.9 ± 0.6 | 15.0 ± 0.5 | 12.8 ± 0.1 | 30.6 ± 0.9 | 15.5 ± 1.0 | 10.8 ± 1.6 | 14.9 ± 0.4 | 6.8 ± 0.4 | 2.61 ± 0.01 |
| | | E-$O_3$ | 20.5 ± 1.3 | 18.6 ± 0.5 | 12.4 ± 1.1 | 31.7 ± 3.0 | 13.8 ± 0.8 | 15.7 ± 0.5 | 16.3 ± 1.4 | 10.2 ± 0.9 | 2.73 ± 0.11 |
| Ⅱ | LD | C-$O_3$ | 19.0 ± 0.5 | 14.7 ± 1.6 | 10.3 ± 0.5 | 23.2 ± 0.4 | 26.5 ± 1.0 | 12.7 ± 0.7 | 16.9 ± 1.6 | 6.36 ± 0.4 | 2.26 ± 0.16 |
| | | E-$O_3$ | 17.7 ± 1.2 | 13.0 ± 0.9 | 11.1 ± 0.4 | 24.6 ± 1.6 | 27.6 ± 0.7 | 13.4 ± 0.9 | 18.0 ± 1.4 | 6.66 ± 0.1 | 2.47 ± 0.13 |
| | MD | C-$O_3$ | 21.6 ± 1.3 | 14.1 ± 0.2 | 10.5 ± 0.6 | 22.6 ± 1.3 | 24.3 ± 0.6 | 11.7 ± 1.6 | 15.0 ± 0.5 | 6.05 ± 0.1 | 2.44 ± 0.07 |
| | | E-$O_3$ | 16.9 ± 0.9 | 13.7 ± 1.6 | 11.0 ± 0.4 | 26.2 ± 1.1 | 25.3 ± 1.9 | 12.5 ± 0.7 | 16.7 ± 1.5 | 6.42 ± 0.4 | 2.49 ± 0.14 |
| | HD | C-$O_3$ | 17.0 ± 1.1 | 15.3 ± 1.1 | 10.5 ± 0.5 | 22.8 ± 1.5 | 23.4 ± 1.4 | 12.5 ± 1.4 | 14.9 ± 1.2 | 6.44 ± 0.2 | 2.38 ± 0.02 |
| | | E-$O_3$ | 16.5 ± 0.2 | 14.6 ± 0.4 | 12.1 ± 0.4 | 28.2 ± 0.6 | 27.3 ± 1.3 | 14.1 ± 0.4 | 17.6 ± 1.0 | 6.59 ± 0.1 | 2.58 ± 0.07 |
| A | *P*-v | C | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.707 | 0.108 | 0.000 | 0.000 |
| | | D | 0.063 | 0.919 | 0.404 | 0.545 | 0.364 | 0.787 | 0.527 | 0.688 | 0.473 |
| | | $O_3$ | 0.221 | 0.162 | 0.432 | 0.018 | 0.629 | 0.015 | 0.023 | 0.006 | 0.024 |
| | | $O_3$×C | 0.022 | 0.005 | 0.003 | 0.529 | 0.057 | 0.236 | 0.718 | 0.020 | 0.876 |
| | | $O_3$×D | 0.791 | 0.485 | 0.254 | 0.362 | 0.783 | 0.223 | 0.869 | 0.847 | 0.670 |
| | | $O_3$×C×D | 0.239 | 0.822 | 0.568 | 0.505 | 0.564 | 0.437 | 0.897 | 0.753 | 0.910[1] |

*C: Cultivar; t: treatment; D: Density; T: Tillering; J: Jointing; H: Heading; M: Maturity

A: ANOVA; Ⅱ: Ⅱ you084; Y: Yangdao6; P-V: P-value

**Table 2:** Effects of surface ozone concentration and plant density on K concentration in plant of rice under FACE condition

| Cultivar | Density | $O_3$ treatment | Tillering stage (mg $g^{-1}$) | Jointing stage (mg $g^{-1}$) | Heading stage (mg $g^{-1}$) | Maturity stage (mg $g^{-1}$) |
|---|---|---|---|---|---|---|
| Yangdao6 | LD | C-$O_3$ | 25.9 ± 0.7 | 17.0 ± 0.7 | 12.6 ± 0.9 | 7.2 ± 0.1 |
| | | E-$O_3$ | 25.6 ± 0.4 | 15.6 ± 0.7 | 12.8 ± 0.7 | 8.0 ± 0.7 |
| | MD | C-$O_3$ | 23.1 ± 1.4 | 16.6 ± 0.8 | 12.1 ± 0.9 | 7.4 ± 0.1 |
| | | E-$O_3$ | 26.7 ± 0.7 | 14.4 ± 0.7 | 12.7 ± 1.2 | 6.0 ± 1.2 |
| | HD | C-$O_3$ | 21.4 ± 3.7 | 15.3 ± 0.8 | 9.3 ± 1.6 | 7.5 ± 0.1 |
| | | E-$O_3$ | 25.9 ± 1.7 | 13.6 ± 1.4 | 14.9 ± 0.5 | 7.6 ± 0.7 |
| Ⅱ you084 | LD | C-$O_3$ | 21.1 ± 0.4 | 20.4 ± 1.1 | 10.6 ± 0.6 | 6.7 ± 0.4 |
| | | E-$O_3$ | 21.1 ± 0.4 | 19.7 ± 0.6 | 11.4 ± 0.7 | 7.4 ± 0.3 |
| | MD | C-$O_3$ | 22.1 ± 1.1 | 19.1 ± 0.2 | 10.1 ± 0.8 | 6.7 ± 0.4 |
| | | E-$O_3$ | 21.2 ± 0.9 | 19.2 ± 1.4 | 10.8 ± 0.3 | 7.0 ± 0.3 |
| | HD | C-$O_3$ | 19.7 ± 1.3 | 19.3 ± 1.0 | 10.6 ± 0.8 | 6.7 ± 1.0 |
| | | E-$O_3$ | 22.1 ± 0.4 | 20.6 ± 1.1 | 12.0 ± 0.3 | 7.3 ± 0.6 |
| ANOVA | *P*-value | Cultivar | 0.000 | 0.000 | 0.001 | 0.029 |
| | | Density | 0.966 | 0.585 | 0.843 | 0.730 |
| | | $O_3$ | 0.158 | 0.462 | 0.011 | 0.106 |
| | | $O_3$×C | 0.469 | 0.814 | 0.536 | 0.636 |
| | | $O_3$×D | 0.509 | 0.658 | 0.172 | 0.905 |
| | | $O_3$×C×D | 0.123 | 0.790 | 0.396 | 0.847 |

**Table 3:** Effects of surface ozone concentration and plant density on K accumulation in plant of rice under FACE condition

| Cultivar | Density | $O_3$ treatment | Tillering stage (mg $g^{-1}$) | Jointing stage (mg $g^{-1}$) | Heading stage (mg $g^{-1}$) | Maturity stage (mg $g^{-1}$) |
|---|---|---|---|---|---|---|
| Yangdao6 | LD | C-$O_3$ | 3.3 ± 0.3 | 7.4 ± 0.4 | 10.6 ± 0.1 | 12.6 ± 0.7 |
| | | E-$O_3$ | 3.1 ± 0.3 | 7.5 ± 0.4 | 9.0 ± 0.7 | 10.7 ± 0.3 |
| | MD | C-$O_3$ | 3.7 ± 0.2 | 7.6 ± 0.4 | 12.4 ± 1.3 | 13.3 ± 0.6 |
| | | E-$O_3$ | 4.1 ± 0.2 | 7.6 ± 0.4 | 10.9 ± 1.2 | 12.0 ± 1.1 |
| | HD | C-$O_3$ | 4.6 ± 0.7 | 8.2 ± 0.3 | 10.4 ± 1.5 | 13.3 ± 0.6 |
| | | E-$O_3$ | 4.0 ± 0.4 | 7.5 ± 1.1 | 11.1 ± 0.8 | 12.9 ± 0.6 |
| Ⅱ you084 | LD | C-$O_3$ | 2.4 ± 0.1 | 9.3 ± 0.6 | 10.5 ± 1.0 | 11.3 ± 0.5 |
| | | E-$O_3$ | 2.1 ± 0.2 | 7.8 ± 0.5 | 9.4 ± 0.7 | 8.8 ± 0.3 |
| | MD | C-$O_3$ | 3.4 ± 0.5 | 9.8 ± 0.5 | 10.8 ± 0.5 | 11.6 ± 0.7 |
| | | E-$O_3$ | 2.8 ± 0.2 | 9.0 ± 0.6 | 9.8 ± 0.6 | 9.1 ± 0.5 |
| | HD | C-$O_3$ | 3.3 ± 0.2 | 11.3 ± 1.1 | 11.0 ± 1.1 | 12.8 ± 1.0 |
| | | E-$O_3$ | 3.2 ± 0.2 | 11.0 ± 0.7 | 10.5 ± 1.1 | 10.7 ± 0.5 |
| ANOVA | *P*-value | Cultivar | 0.000 | 0.000 | 0.906 | 0.001 |
| | | Density | 0.000 | 0.020 | 0.074 | 0.015 |
| | | $O_3$ | 0.292 | 0.210 | 0.543 | 0.000 |
| | | $O_3$×C | 0.524 | 0.416 | 0.793 | 0.043 |
| | | $O_3$×D | 0.769 | 0.932 | 0.129 | 0.267 |
| | | $O_3$×C×D | 0.182 | 0.710 | 0.941 | 0.417 |

## Discussion

The previous studies reported varied response to increased ozone concentration on absorbing and use of K in various crops. One and a half times ozone concentration than in atmosphere had little effect on the level of K in the wheat tissues, showed by an OTC experiment (Fangmeier *et al.*, 1997, 1999). The increased ozone concentration decreased the K level in leafs of all tested varieties in rice solution culture experiment in closed air chamber (Welfare *et al.*, 1996). Rai *et al.* (2010) indicated that the increased ozone concentration had little decrease on K level in grains of rice NDR 97 and Saurabh 950. A study on the wheat (Fuhrer *et al.*, 1990) showed that the increased ozone concentration reduces the K accumulation in wheat at each growth stage, decreases the K level in leafs at the maturity stage somewhat, but rises in spike. In another study, (Pleijel *et al.*, 1998) showed that the increase of ozone concentration promotes wheat to absorb K during whole crop growth period, and increases the K level in its grain at the same time. This study indicated that the K level in each organ of Yangdao 6 at various stages showed an increasing tendency under high ozone concentration and for the whole plant increase by 6% at tillering, 3% at jointing, 10% at heading, and 8% at maturity stages. The K level in different organs of II you 084 at early and middle stages was irregular caused by ozone stress, and of the whole plant changes a little at tillering and jointing stages, but that at heading and maturity stages increased by 9% and 8% separately. It was clear that ozone stress increased the K level in the whole plant of rice in general, especially at heading and maturity stages. The rate of change of K level increased efficiency and dry matter production decreased efficiency co-existed under ozone stress influenced jointly the variation of K accumulation. In terms of the study results, high ozone concentration had little effect on the K accumulation of Yangdao 6 at tillering, jointing and heading stages, but was lowered by 9% at maturity. For II you 084, the dry matter production decreased efficiency is much higher than the K level increased efficiency under ozone stress, and K accumulation declined 10% at tillering, 8% at jointing, 8% at heading, and 20% at maturity stages. These are evident with the study results in wheat (Pleijel *et al.*, 1998).

In terms of K distribution, high ozone concentration had irregular effects on its ratio in each organ of rice. Generally, under ozone concentration, the K distribution ratio in green leafs decreased, and in stems increased at early stages but decreased at heading and maturity stages, and that grain increased at heading stage but changed a little at maturity stage. Therefore, ozone stress can increase the K distribution ratio in stems of plants at early growth stage, but decreased gradually that at middle and later stages, and make little difference in each organ at maturity.

In terms of the K use efficiency, the K matter production efficiency showed that the dry matter accumulation produced by rice absorbing K.

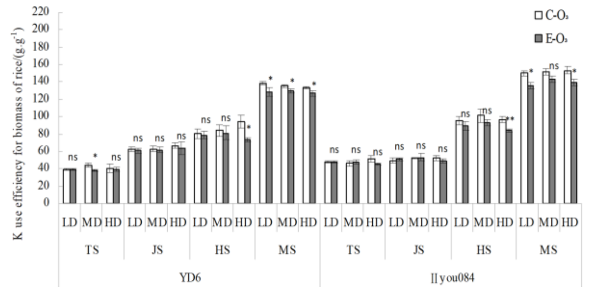


**Fig. 2:** Effects of surface ozone concentration and plant density on K use efficiency for biomass of rice under FACE condition

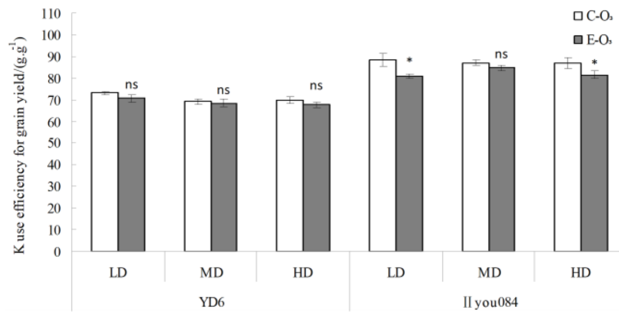


**Fig. 3:** Effects of surface ozone concentration and plant density on K use efficiency for grain yield of rice under FACE condition

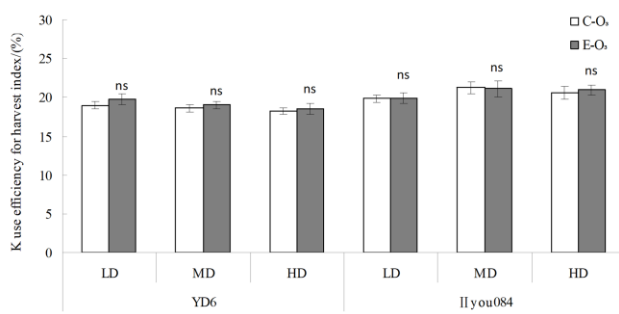


**Fig. 4:** Effects of surface ozone concentration and plant density on K use efficiency for harvest of rice under FACE condition

The effect of ozone on K use efficiency of rice was rarely reported. However, this study indicated that the decreasing amplitude of rice dry matter accumulation under ozone stress was much higher than the increased range of K, hence ozone stress can reduce K dry matter production efficiency of rice at different growth stages, in both varieties. It also lowered the K distribution ratio in grains at maturity as well, and that of II you 084 reduced by 5.8%. Due to ozone stress effects on the K distribution ratio in grains at maturity were little, the K harvest index of Yangdao 6 and II you 084 changed a little under high ozone concentration.

**Table 4:** Effects of surface ozone concentration and plant density on K distribution ratio in the organs of rice under FACE condition

| C | D | $O_3$t | Green leaf | | | Stem | | | | Spike | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | T stage (%) | J stage (%) | H stage (%) | T stage (%) | J stage (%) | H stage (%) | M stage (%) | H stage (%) | M stage (%) |
| Y | LD | C-$O_3$ | 42.7 ± 0.2 | 42.4 ± 1.4 | 41.1 ± 1.2 | 57.3 ± 0.9 | 56.0 ± 0.9 | 49.0 ± 1.7 | 64.3 ± 1.3 | 8.6 ± 0.3 | 19.0 ± 0.5 |
| | | E-$O_3$ | 39.8 ± 1.9 | 52.1 ± 2.6 | 38.8 ± 5.3 | 60.2 ± 1.9 | 46.4 ± 2.7 | 49.2 ± 6.4 | 63.7 ± 4.4 | 10.5 ± 1.0 | 19.8 ± 1.7 |
| | MD | C-$O_3$ | 45.8 ± 1.0 | 44.2 ± 2.0 | 40.4 ± 1.8 | 54.2 ± 1.0 | 53.5 ± 2.2 | 51.2 ± 2.0 | 65.3 ± 1.1 | 7.6 ± 0.6 | 18.6 ± 0.5 |
| | | E-$O_3$ | 43.5 ± 2.9 | 52.3 ± 2.2 | 35.7 ± 1.1 | 56.5 ± 2.9 | 45.3 ± 2.1 | 52.9 ± 3.0 | 66.1 ± 1.7 | 9.5 ± 0.9 | 19.0 ± 0.8 |
| | HD | C-$O_3$ | 42.9 ± 4.2 | 43.6 ± 2.9 | 37.2 ± 5.7 | 57.1 ± 4.2 | 54.3 ± 2.2 | 52.7 ± 3.1 | 65.5 ± 1.7 | 8.6 ± 0.8 | 18.2 ± 0.4 |
| | | E-$O_3$ | 40.0 ± 3.1 | 48.5 ± 5.0 | 28.7 ± 3.2 | 60.0 ± 3.1 | 47.9 ± 5.0 | 59.4 ± 2.2 | 70.1 ± 3.9 | 10.8 ± 0.9 | 18.6 ± 2.0 |
| Ⅱ | LD | C-$O_3$ | 46.3 ± 0.6 | 37.1 ± 2.7 | 28.0 ± 1.7 | 53.7 ± 0.6 | 62.9 ± 2.7 | 59.7 ± 1.0 | 69.8 ± 2.0 | 11.1 ± 1.6 | 19.9 ± 1.1 |
| | | E-$O_3$ | 44.1 ± 2.4 | 34.9 ± 1.1 | 30.8 ± 1.5 | 55.9 ± 4.4 | 65.1 ± 1.1 | 59.2 ± 2.1 | 64.8 ± 2.0 | 9.3 ± 0.6 | 19.9 ± 0.9 |
| | MD | C-$O_3$ | 51.0 ± 2.7 | 37.9 ± 1.2 | 29.3 ± 3.3 | 49.0 ± 2.7 | 62.1 ± 1.2 | 57.5 ± 3.9 | 68.0 ± 1.7 | 11.8 ± 1.4 | 21.2 ± 1.7 |
| | | E-$O_3$ | 42.4 ± 2.0 | 37.4 ± 1.8 | 30.5 ± 1.4 | 57.6 ± 2.0 | 62.6 ± 2.8 | 57.9 ± 1.8 | 61.9 ± 1.9 | 10.6 ± 0.9 | 21.1 ± 1.0 |
| | HD | C-$O_3$ | 44.9 ± 0.9 | 41.1 ± 3.1 | 29.9 ± 1.4 | 55.1 ± 0.9 | 58.9 ± 3.1 | 57.9 ± 2.5 | 65.5 ± 2.4 | 10.7 ± 1.3 | 20.6 ± 2.7 |
| | | E-$O_3$ | 39.0 ± 1.3 | 38.1 ± 2.3 | 31.2 ± 1.7 | 61.0 ± 1.3 | 61.9 ± 2.3 | 57.8 ± 1.6 | 63.3 ± 4.4 | 9.8 ± 0.5 | 20.9 ± 1.4 |
| A | *P*-v | C | 0.223 | 0.000 | 0.000 | 0.223 | 0.000 | 0.005 | 0.937 | 0.204 | 0.879 |
| | | D | 0.038 | 0.897 | 0.404 | 0.038 | 0.720 | 0.515 | 0.789 | 0.957 | 0.933 |
| | | $O_3$ | 0.012 | 0.110 | 0.160 | 0.012 | 0.066 | 0.275 | 0.172 | 0.623 | 0.540 |
| | | $O_3$×C | 0.227 | 0.006 | 0.020 | 0.227 | 0.003 | 0.263 | 0.056 | 0.047 | 0.599 |
| | | $O_3$×D | 0.836 | 0.841 | 0.698 | 0.836 | 0.904 | 0.774 | 0.240 | 0.990 | 0.876 |
| | | $O_3$×C×D | 0.414 | 0.977 | 0.883 | 0.414 | 0.939 | 0.794 | 0.689 | 0.922 | 0.866[1] |

[*]C: Cultivar; D: Density; t: treatment; T: Tillering; J: Jointing; H: Heading; M: Maturity

*P*-V: *P*-value; A: ANOVA; Y: Yangdao6; Ⅱ: Ⅱyou084

**Table 5:** The ANOVA results (*p value*) of surface ozone concentration and plant density on K use efficiency of rice

| Items | K use efficiency for biomass | | | | K use efficiency for grain yield | K use efficiency for harvest |
|---|---|---|---|---|---|---|
| | Tillering stage | Jointing stage | Heading stage | Maturity stage | | |
| Cultivar | **0.002** | **0.007** | **0.036** | **0.041** | **0.003** | 0.328 |
| Density | 0.563 | 0.327 | 0.671 | 0.213 | 0.321 | 0.287 |
| $O_3$ | 0.327 | 0.512 | **0.002** | **0.005** | **0.087** | 0.467 |
| $O_3$× Cultivar | 0.763 | 0.629 | 0.671 | 0.423 | 0.542 | 0.672 |
| $O_3$× Density | 0.689 | 0.472 | 0.872 | 0.649 | 0.439 | 0.826 |
| $O_3$× Cultivar× Density | 0.823 | 0.798 | 0.639 | 0.743 | 0.672 | 0.528 |

## Conclusion

The results of this study indicated that high ozone concentration increases the K level in rice, but decreases its accumulation and utilization significantly. This study further showed that the high ozone stress through various planting densities had no effect on absorption, distribution and use of K in rice, but the K accumulation of conventional and hybrid rice varieties at maturity responded a lot to ozone stress, which indicates that, in the future environment with high ozone concentration, increasing K fertilizer properly may release the stress effect of absorbing K to some extent for hybrid rice variety, and thereby may reduce the production losses. These results provide evidence that varied response of different rice varieties or atmosphere conditions needs further studies to answer.

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