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Full Length Research Paper

Competition between cultivated rice (*Oryza sativa*) and wild rice *(Oryza punctata)* in Kenya

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This shade house study examined the effect of competition on the growth performance of cultivated (*Oryza sativa*) and wild (*Oryza punctata*) rice species in Kenya. Growth was assessed for the two species, grown together and separately, by measuring plant height and tiller number through the growing season, and flag leaf area and above and below-ground biomass at the end of the growing season. *O. punctata* grew to a higher final height (116.00 ± 13.63 cm) attained higher tiller number (9 tillers /plant) and accumulated more biomass (16.68 ± 0.50 g) than *O. sativa* while *O. sativa* attained a higher flag leaf area (35.00 ± 0.67 cm^2) than *O. punctata* (P<0.05). For both species, interspecific competition was detected as a reduction in flag leaf area, (1.4 and 2.5 cm^2) for *O. punctata* and *O. sativa* respectively. Flag leaf area is known to relate directly to grain yield. It was concluded that *O. punctata* is a better competitor than *O. sativa* (P<0.05) as it had more aggressive vegetative growth, less reduction in flag leaf area, attained higher final plant height and phytomass and matured faster than *O. sativa*.

Key words: Competition, growth, *Oryza sativa*, *Oryza punctata,* cultivated rice, wild rice.

INTRODUCTION

The genus *Oryza* has 25 species distributed throughout tropical and subtropical regions of all continents (Veasey et al., 2004). The cultivated species of rice are *Oryza sativa* Linn and *Oryza glaberrima* Staud. *O. sativa* originnates from South-East Asia and is grown worldwide whereas *O. glaberrima* is grown solely in West Africa, its area of origin (Linares, 2002; Fageria and Baligar, 2003).

Rice is an important staple food for more than 50% of the world's population (Fageria and Baligar, 2003). In Kenya, it is the third most important cereal crop after maize and wheat. It is the major part of the diet for the urban populations and it is gaining popularity in the rural areas. About 95% of the rice in Kenya is grown under irrigation paddy schemes managed by the National Irrigation Board (NIB). The remaining 5 per cent is rainfed. Most of the rain fed rice is grown in Kwale, Kilifi, and Tana River districts in the Coast Province, and Bunyala and Teso districts in the western Kenya (Anonymous, 2005). Kenya's rice production comes from cultivated rice (*O. sativa*) and meets only 60% of the demand (Wanjogu and Mugambi, 2001). Therefore, there is a strong need to increase the current rice production levels, and also to come up with supplements for the cultivated rice using wild varieties such as *O. punctata* (Vaughan, 1994).

Wild rice, *O. punctata* is commonly found as a weed in the cultivated rice fields of *O. sativa* in the coastal region of Kenya. It has been cited as a potential food supplement for *O. sativa* during famine in Kenya (Vaughan, 1994). However, it is currently not consumed in the country though cited as a potential food supplement and the consumed rice purely comes from *O. sativa*. Advantages of *O. punctata* over *O. sativa* include faster maturity rate (100 days) compared to *O. sativa* (130 days), it can grow in saline conditions (Fischer and Ramirez, 1993), it grows in swampy areas and does not need as much water as *O. sativa* (Diarra et al., 1985). Since it thrives in diverse environmental conditions, it can be grown in a wider geographical area than *O. sativa*. Despite the above advan-

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Abbreviations: OP, O. *punctata* from monoculture**; OPOS***, O. punctata* from *O. punctata/ O.* *sativa* mixture**; OS***, O. sativa* from monoculture; **OSOP**, *O. sativa* from *O. punctata/ O. sativa* mixture.

tages, *O. punctata* is considered as one of the most problematic weeds in Kenya. It grows together in competition with *O. sativa*.

Weed-crop competition is one of the major causes of crop yield loss (Cao et al., 2007). Weedy rice commonly causes a considerable reduction in cultivated rice yield because of its competition for resources. The extent of yield losses depend on weed density (Fischer and Ramirez, 1993), type of weedy plants (Diarra et al., 1985), the variety of rice grown (Elefhterohorinos et al., 2002) and competition duration (Kwon et al., 1991). Yield loss due to weedy rice can be expressed not only in the quantity of the rice harvest (Estorninos et al., 2000) but also in a decreased quality of the grain (Kwon et al., 1991; Pantone and Baker, 1991).

Studies on competition between cultivated and wild rice are lacking in Kenya. This study therefore dealt with competition between the cultivated rice, *O. sativa*, and wild rice, Oryza punctata and its effect on the plant growth of the two species. An improved understanding of the growth characteristics of *O. punctata* and its impact on the growth of cultivated rice has two benefits: (1) To recommend the best cropping system if *O. punctata* is introduced in farming systems as a supplement to *O. sativa*. This is very important to small-scale farmers who do not own large farms for rice cultivation. This will enable them to supplement their low *O. sativa* production. (2) With the potential advent of herbicide-resistant *O. sativa,* there is a risk that *O. punctata* will acquire the resistance gene from the crop and turn it into a weed that is difficult to control. It has been reported (Estorninos et al., 2002; Gealy et al., 2003) that the genetic, physiological, and morphological similarities in cultivated and wild rice provide opportunities for the transfer of the herbicide-resistant traits, especially if flowering is synchronous. To assess the importance of that risk, it is important to know how harmful *O. punctata* is as a weed in a field of *O. sativa*.

Biomass accumulation is a good measure of competitive success, because it reflects resource capture under the interference of neighbours (Fernando et al., 2006; Gaudet and Keddy, 1988; Roush and Radosevich, 1985). Above-and below-ground biomass accumulation was therefore used in this study as a measure of competitive success. The objective of this study was to compare the growth performance of *O. sativa* and *O. punctata* when grown together and when grown separately under similar conditions. *O. punctata* was found to be the stronger competitor as it grew faster and attained a higher above- and below-ground biomass than *O. sativa*.

MATERIALS AND METHODS

Plant materials

The *O. sativa* (Basmati 370-Pishori) seeds used in this study were obtained from Tana Delta Irrigation Scheme in Tana River District, Coast Province of Kenya (2° 11’ S, 40° 10’ E). This rice variety has been grown in Kenya since the 1960s. *O. punctata* seeds were randomly collected from the fields within the Tana Delta Irrigation Scheme. The site was chosen since the two species naturally occur together within this region. The close proximity of the material collecting sites for the two species ensured that the seeds were exposed to similar conditions before the start of the study.

Shade house experiment

The study was conducted from January 2007 to October 2007 in a shade house covered with polythene paper at Chiromo campus, University of Nairobi (1° 16' S, 36° 48' E). Although there were differences in latitudes between the material collection site (Coast Province) and the experimental site (Nairobi Province), the objecttive of the study was to compare the basic biological characteristics of the cultivated and wild rice under the same environmental conditions. Therefore the difference would not affect the basic conclusions.

Three treatments were designed for the experiment namely; *O. sativa* grown separately, *O. punctata* grown separately and the two species grown together. Each treatment included three replicates that were arranged in plastic basins of 0.70m diameter each. The experiment therefore included a total of 9 replicates per block which were arranged in a randomized complete block design (Steel et al., 1997). A total of six blocks was used. The seeds of the two species were sown into separate basins on the same day. The soil type used was black clay (Vaughan, 1994) which was similar to the soil in the area from where the seeds were collected. Each basin was three-quarter filled with the soil. Twenty-one-day-old seedlings were transplanted into the experimental basins on 27 March and harvested on 20 October 2007. Twenty seedlings were transplanted into each basin at a spacing of 10cm by 10 cm and sowing depth of 3 cm. The total number of seedlings per block for all treatments was 180. Six blocks were used giving a total of 1080 seedlings for the whole experiment. In the mixed planting, the two species were randomly planted.

Ten seedlings from each basin were marked and used for all subsequent sampling. Data were collected on plant height, number of tillers per plant, flag leaf area of the first tiller, and above- and below-ground dry phytomass. Plant height was taken on a weekly basis. For seedling, vegetative and reproductive stages, height was measured from base to the tip of the tallest leaf. At ripening and maturity stages, it was measured from the base to the tip of the tallest panicle (Yoshida, 1981). Number of emerging tillers was counted weekly from first tiller emergence to maximum tillering stage. Flag leaf area (A) was determined at maturity by measuring the length (L) and width (W) of the leaf to a precision of 1 mm. Flag leaf area (A) was then calculated as $A = 0.67LW$ (Yoshida, 1981).

At the end of the experiment, all the plants from each basin were uprooted, labelled and the roots washed to remove any adhering soil particles. The 10 marked plants from each basin were sorted out and separated into above- and below-ground dry material by cutting with a sharp knife at the soil surface level (Pande, 1994). The mass of each sample was then determined to a precision of 0.05 g after oven drying at 80℃ to a constant mass.

Statistical analyses

The growth curves of plant height and tiller number were found by regression using the least squares method (Table Curve software, SYSTAT, Richmond, California). Among the sigmoid equations provided by this software, one was chosen that gave the overall least bias when studying the residuals. The parameters describing the growth curve were compared between treatments using a *t*-test with $\alpha = 5\%$ for each comparison.

Flag leaf area and above- and below-ground phytomass data

Table 1. Parameters for the curve (Eq. 1) describing growth in plant height and number of tillers per hill (average±s.e.) for *O. punctata* grown alone (OP), *O. punctata* grown together with *O. sativa* (OPOS), *O. sativa* grown alone (OS) and *O. sativa* grown together with *O. punctata*, (OSOP). Comparisons between treatments were either non-significant (*ns*) or significant (*) at the 5% level.

Parameter					OP *vs.* OPOS	OS *vs.* OSOP	OP *vs.* OS
Plant height							
y_{init} (cm)	8.82±10.49	3.32±9.86	8.32±1.75	7.44±2.31	ns	ns	ns
y_{end} (cm)	116.00±13.63	96.9±8.30	84.20±2.07	79.40±2.58	ns	ns	*
x_{mid} (days)	69.00±7.28	62.80±5.27	84.10±0.92	83.00±1.39	ns	ns	ns
w (days)	16.20±11.79	10.40±6.00	6.70±1.74	9.68±2.83	ns	ns	ns
α (-)	0.80±1.35	0.31±0.31	0.26±0.10	0.37±0.18	ns	ns	ns
Tiller number							
y_{init} (-)	–2.12±1.81	–1.32±2.20	–0.004±0.11	–0.02±0.16	ns	ns	ns
y_{end} (-)	9.07±1.82	5.74±2.09	4.43±0.16	4.34±0.21	ns	ns	*
x_{mid} (days)	51.51±9.79	49.41±16.03	56.37±0.81	58.56±0.99	ns	ns	ns
w (days)	2.20±2.83	6.84±6.50	7.13±1.88	5.97±2.20	ns	ns	ns
α (-)	0.05±0.08	0.19±0.35	2.17±2.56	1.12±1.34	ns	ns	ns

analysis was carried out by analysis of variance using the statistical program SPSS version 14. The significantly different parameters at 5% significance level were separated using the Student-Newman-Keuls test (Steel et al., 1997).

RESULTS

Plant height and tiller number

Of the sigmoid functions tested, including the Gompertz and the logistic functions (Peters, 1993), most resulted in biased residuals. In this respect, the asymmetric sigmoid function yielded the best fit to the height and tiller number measurements:

$$y = y_{init} + \frac{y_{inc}}{\left[1+\exp\left\{-\frac{x - w\ln\left(2^{1/\alpha}-1\right) - x_{mid}}{w}\right\}\right]^{\alpha}} \quad \text{(Eq. 1)}$$

Where, y is height or tiller number, and x is the number of days after transplanting. The five parameters of the curve have this interpretation,

y_{init}: initial height (cm) or tiller number;
y_{inc}: final increment in height (cm) or tiller number;
x_{mid}: the time at which half the final height or tiller number is achieved (days);
w: width of the growth curve (days), smaller values giving a steeper curve;
α: curve asymmetry (dimensionless); α=1 for symmetric curves; α>1 when the first bend of the curve is sharper than the second bend; α<1 when the second bend is sharper.

The only significant P< 0.001) differences found in the parameters of Eq. 1 were between the two species: *O. punctata* grew to a larger final height and it produced more tillers than *O. sativa* (Table 1). The species also differed in development rate, *O. punctata* flowering and reaching maturity about 1 month before *O. sativa* (Figure 1). There was a seeming reduction of growth, both in terms of height and tiller number, caused by competition; that is, compare OP *vs.* OPOS and OS *vs.* OSOP in Figure 1. Due to the large variances, especially in *O. punctata* (Table 1), effects of competition in relation to plant height and tiller numbers were not statistically detected. At maturity *O. punctata* produced grain that shattered quickly, while *O. sativa* did not produce any grains.

Table 2. Flag leaf area (mean ± S.E.) for *O. punctata* grown alone (OP), *O. punctata* grown with *O. sativa* (OPOS), *O. sativa* grown alone (OS), and *O. sativa* grown with *O. punctata* (OSOP).

Treatments	Flag leaf area (cm^2)
OP	26.1±0.67[a]
OPOS	24.7±0.55[b]
OS	35.0±0.67[c]
OSOP	32.5±0.72[d]

Averages followed by different letters were significantly different (P<0.05)

Flag leaf area

O. sativa whether grown alone or in the mixture attained a higher flag leaf area than *O. punctata* (P<0.001, Table 2). For both species, the monocultures attained higher flag leaf area than the mixtures (P<0.001). Flag leaf area of the two species was therefore reduced by competition, but more reduction (2.5 cm^2) in *O. sativa* than in *O. punc*

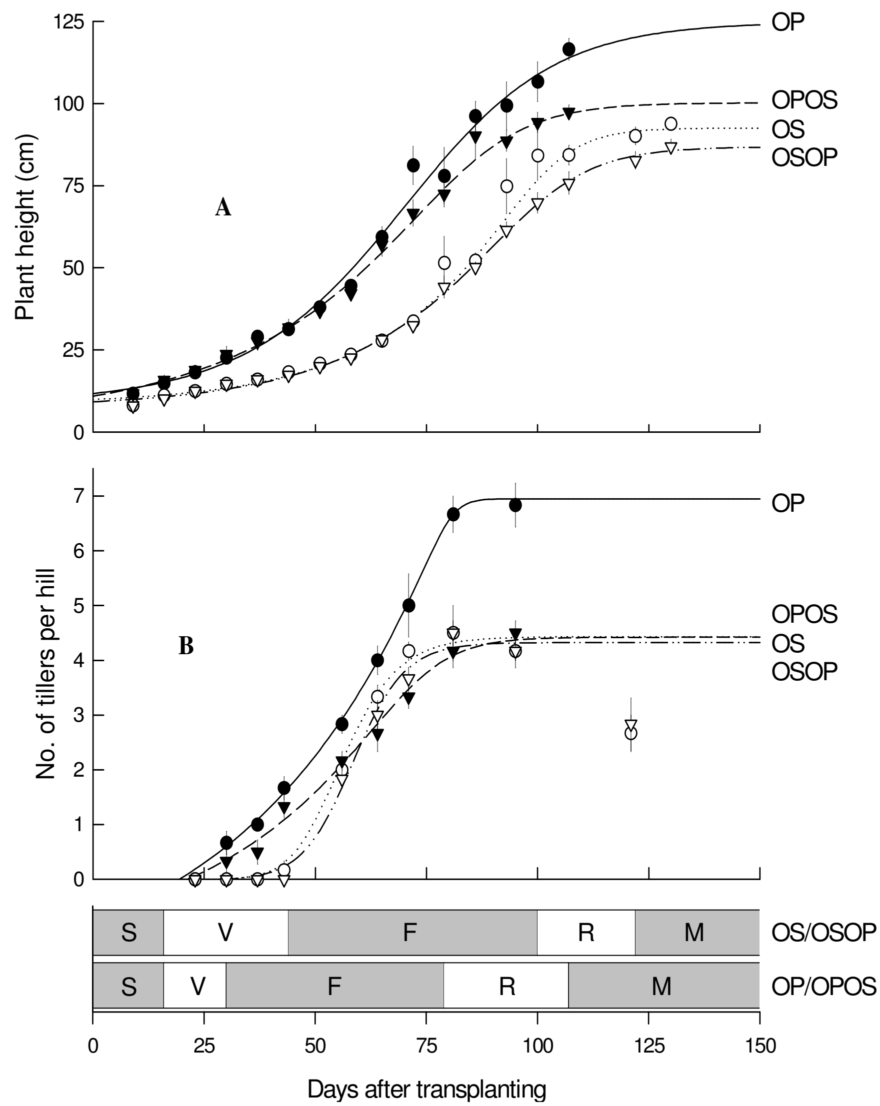

Figure 1. Growth in plant height (**A**) and tiller number (**B**) after transplantation for *O. punctata* grown alone (OP), *O. punctata* grown together with *O. sativa* (OPOS), *O. sativa* grown alone (OS) and *O. sativa* grown together with *O. punctata*, (OSOP). Points show Mean ± S.E. Curves show Eq. 1 fitted to each data series (Table 1). Growth stages given as (S) seedlings, (V) vegetative, (F) reproductive (R) ripening and (M) maturity were not affected by competition.

tata (1.4 cm^2) and hence *O. punctata* was a better competitor.

Phytomass

Phytomass at harvest showed the same pattern in the above- ground as that in the below-ground, whereby *O. punctata* grown alone grew to a higher height than when in competition with *O. sativa*, whereas *O. sativa* was not affected by competition (P>0.001), and *O. punctata* attained higher mass than *O. sativa* both with and without competition (Figure 3).

DISCUSSION

The wild rice (*O. punctata*) had higher vegetative growth than the cultivated rice (*O. sativa*). This was expressed both in terms of more tillers and higher final plant height and plant biomass. This in itself will make *O. punctata* the stronger competitor in the growing season than *O. sativa*. Moreover it developed quicker (De Datta et al., 1981; Diarra et al., 1985; Kwon et al., 1991), and its seeds, which shattered readily, would be cast in the field before crop harvest. This makes *O. punctata* a difficult weed to control in the long run; after the seeds have entered the

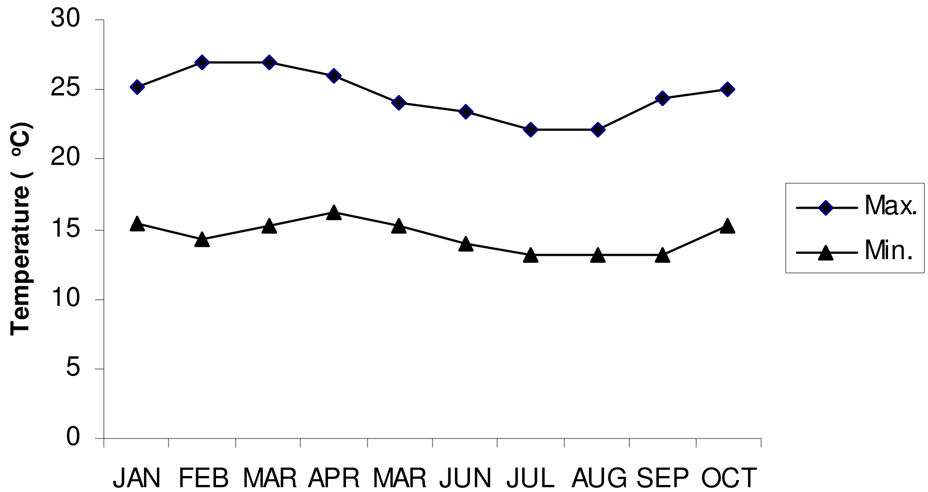

Figure 2. Monthly average of the daily minimum and maximum Shade house (°C).

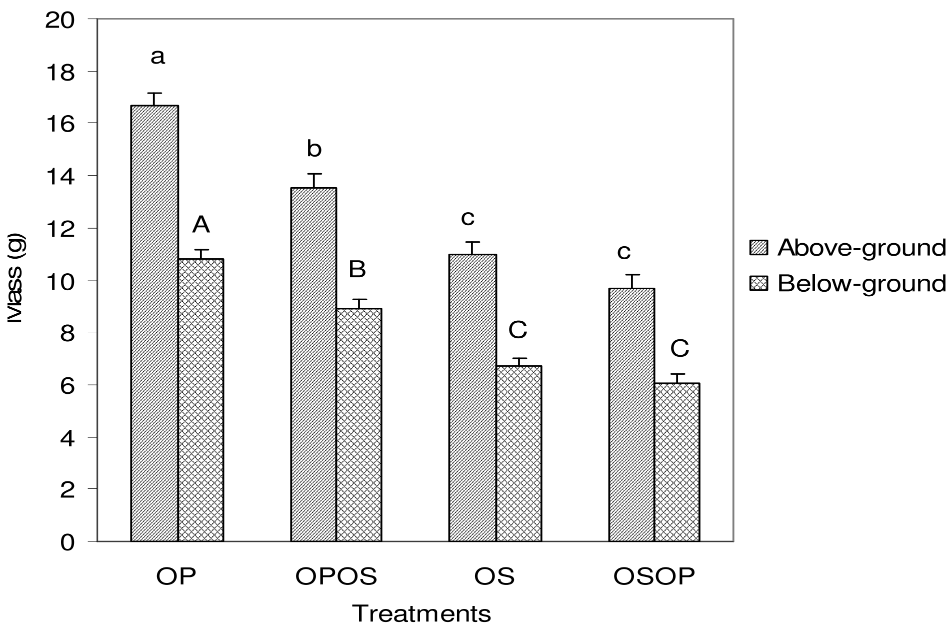

Figure 3. Above- and below-ground phytomass for *O. punctata* grown alone (OP), *O. punctata* grown with *O. sativa* (OPOS), *O. sativa* grown alone (OS), and *O. sativa* grown with *O. punctata* (OSOP). Bars show Mean ± S.E. Means with the same letter (a-c or A-C) were not different at the 5% level.

seed bank they can remain dormant for many years (Naredo et al., 1998).

Grain yield was not measured directly due to quick shattering of *O. punctata* seeds and no grain production by *O. sativa*. Lack of grain production by *O. sativa* was possibly due to the generally cool climate that prevailed during the period of study (Figure 2). However, flag leaf area provides a good indirect measurement, as it is well correlated with grain yield (Yoshida, 1981; Dutta et al., 2002). Under this assumption, *O. sativa* would give a higher yield than *O. punctata*, which just confirms that *O. sativa* has been bred for a high yield. Flag leaf area was the growth trait most responsive to competition: for both species the area was reduced by interspecific competition. Thus weeds in rice are more likely to cause a reduction in yield than in vegetative growth traits, such as height, tillering and biomass. Flag leaf area was higher in *O. sativa* than in *O. punctata* but reduction in flag leaf area was less in *O. punctata* (1.4 cm^2) than in *O. sativa* (2.5 cm^2) under competition. *O. punctata* was therefore a better competitor than *O. sativa*.

The wild *O. punctata* was in general more variable (Table 1) than the bred *O. sativa*. This made it more cumbersome to work with, and it introduced variance in the results that made it difficult to separate means. It is recommended that future experiments be designed with more replicates for wild species than for bred cultivars to minimize the variance.

Tall rice cultivars are in general more competitive than those with short stature (McGregor et al*.,* 1988; Kwon et al., 1991; Fischer et al., 1995), as are cultivars with a high tillering ability (McGregor et al*.,* 1988; Fischer et al., 1995; Gealy et al., 1998; Estorninos et al., 2002). The stronger vegetative growth of *O. punctata* would thus give it an advantage over *O. sativa* in competition for light.

Higher tiller production increases the ability of a rice plant to expand rapidly into an available space (Johnson et al., 1998), in addition to its ability to produce more panicles. Estorninos et al. (2002) pointed out that rice cultivars that produced more tillers also produced higher biomass. In this study, *O. punctata* produced a higher biomass both above and below-ground. High tillering capacity, as demonstrated by *O. punctata*, should therefore be considered when breeding for rice cultivars that are competitive against weeds. This agronomic characteristic of rice may improve the success of reduced herbicide rate application programs.

It has been reported (Roush and Radosevich, 1985; Gaudet and Keddy, 1988; Kwon et al., 1991; Fernando et al., 2006) that phytomass accumulation is a good measure of competitive success, because it reflects resource capture under the interference of neighbours. Fleming et al. (1988) reported that the more aggressive species in a mixture increased in shoot weight more than the less aggressive. In this perspective, the aggressive growth form of *O. punctata* would make it a stronger competitor than *O. sativa*. However, we found no effect of inter-specific competition on *O. sativa* phytomass. In contrast, Johnson et al. (1998) found interspecific competition to decrease *O. sativa* shoot phytomass.

With higher below-ground mass, *O. punctata* is likely to be a better competitor for water and nutrients than *O. sativa*. The average root lengths in this study were 20 cm for *O. sativa* and 50 cm for *O. punctata*. It has been reported (Flinn and Garrity, 1986; Dingkuhn et al., 1990; Fofana and Rauber, 2000) that root growth is a dominant characteristic associated with weed competition. Additionally, Fischer et al. (1995) pointed out that early competition in upland rice would be for soil resources, as it occurs before rice and weed canopies overlap. Effects of root competition have been cited by a few other authors (Donald, 1958; Exley and Snaydon, 1992; Perera et al., 1992) as possibly being more important than shoot competition.

We have confirmed farmers' knowledge that *O. punctata*, a widespread weed of cultivated rice in Kenya and elsewhere, can cause serious yield losses due to its aggressive growth and early seed cast. Its rapid growth could make it a valuable crop as it is likely to be more robust: developing quicker and attaining a larger root depth than cultivated rice. If introduced as supplement for *O. sativa*, we recommend a monoculture farming system to avoid competition. Obstacles to grow *O. punctata* as a crop include its tendency to grain shattering and its severe ness as a weed in cultivated rice. If herbicide-resistant rice varieties are taken up there is the additional risk of resistance genes spreading to *O. punctata*, which would make it an even more difficult weed to control.

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